JOURNAL OF AGRICULTURAL RESEARCH

DEPARTMENT OF AGRICULTURE

VOL. VI WASHINGTON, D. C., JULY 17, 1916 No. 16

DIGESTIBILITY OF VERY YOUNG VEAL

By C. F. LANGWORTHY, *Chief*, and A. D. HOLMES, *Scientific Assistant*, *Office of Home Economics, States Relations Service*

INTRODUCTION

Throughout the United States little was known until recently regarding very young veal, since the sale of calves less than 3 to 6 weeks old for food is prohibited by Federal and State laws. Our attitude toward veal, as toward many other foods, has been determined in part by custom and prejudice and in part by economic conditions and experience, often being illogical; therefore it is of interest to ascertain in such cases how far belief is justified by facts, as shown by controlled experimental tests.

That the common opinion that veal is less wholesome than beef and young veal less so than mature veal is not a consistent prejudice against young flesh foods is shown by the common and apparently growing taste which prefers squab to pigeon, ranks broilers as superior to fowls, considers sucking pig a great delicacy, and regards hothouse lamb—that is, lamb less than 3 months old and rapidly grown and fattened—as much superior to older lamb as lamb is to mutton.

That economic conditions may have an effect upon opinion, which is not consistent, is shown by the situation with respect to the marketing of calves. In grazing areas where the cheapness of food makes it possible to rear cattle at least to early maturity there is a natural tendency to do so. In regions where the dairy industry is highly developed, milk is such an important product that it is not thought profitable to rear calves beyond the period when the mother's milk becomes salable, and so, even though they can not be marketed and the producer will seldom care to use on his own table what he is prohibited from selling, they are often slaughtered at from 3 to 6 days old instead of fed until the lawful marketable age.

The prejudice against veal, and more particularly young veal, is inspired chiefly, it would seem, by the belief that it is indigestible, by which is meant either that it causes a digestive disturbance or that it

fails to digest as thoroughly as other meats, with the result that it is either harmful or undesirable as food. That this opinion does not rest on general experience is indicated by the contrary belief in Europe, which ranks veal as a particularly desirable meat, even for invalids, and which regards very young veal much as it does young pig and young lamb.

The question of its dietary value and its digestibility, both in the more popular as well as in the technical sense, thus becomes one worthy of study for itself and for its bearing upon the common prejudice against the use of young veal as well as upon the related matter of wholesomeness when this food is eaten in comparison with more commonly accepted foods, and accordingly the tests here reported were undertaken.

PREVIOUS EXPERIMENTS

In the literature consulted empirical conclusions are not uniform and very little definite information has been found regarding the food value and possible use in the diet of very young veal.

Studies have been made, however, to determine what the difference is, chemically or otherwise, between very young veal and the older market veal. Fish (4),[1] for instance, conducted such an investigation, with the object of obtaining data which would enable him to determine the relative age of the animal in market, so that the very young could be detected. He determined the specific gravity and freezing point of the tissue juice and also the percentage of water, finding that in very young veal, where more water is present in the tissues, there is less depression of the freezing point and a lower specific gravity. In continuation of this work, the same author (5) made dietary studies to determine whether the flesh of the young calf from 1 to 14 days of age exerts any injurious effects upon the consumer. Seven families, including over 20 individuals from 2 to 60 years of age, ate this meat and reported no physiological disturbances, the health of each remaining apparently normal. Later, the results of experiments in vitro led Fish (6) to conclude that the difference in the thoroughness of digestibility of the tissues of very young and market veal is so small as to be practically negligible.

Very recently Berg (3) has reported the experimental data of a biochemical comparison of beef and immature veal in which he discusses the chemical composition, digestion in vitro, and results of feeding experiments made with animals (cats) in the laboratory. He concludes that there are no physiologically significant differences in the chemical composition of beef and immature veal. In a large number of artificial digestion experiments he found that immature veal was as quickly digested as beef. In the feeding experiments with cats, immature veal supplied all of the nitrogen and a large share of the energy of the

[1] Reference is made by number to "Literature cited," p. 587–588.

diet. The animals remained in a normal condition at all times, exhibiting characteristic functions of growth, maintenance, and reproduction. Berg reports that the immature veal at times was kept in an ice box at 2° to 4° C. for many days before use and that it remained in edible condition.

It is evidently the opinion of the more recent investigators that very young veal, or, as it is commonly called, bob veal, is not unsuited for use as human food. As very little information, however, is available as regards the coefficient of digestibility of very young veal, a series of experiments was undertaken to determine the completness of digestion of this material by the human subject in normal health.

DIETARY TESTS

Before attempting to study the digestibility of very young veal, tests were made in which it was cooked in the laboratory and in several homes and eaten in quantity, although no record was kept of the amounts of veal and other foods eaten. The purpose of these tests was to have very young veal prepared by different methods and eaten by a large number of persons whose ages and daily activities were quite varied, to see whether purging or other disturbances of digestion would result and whether there was warrant for the popular belief that it is indigestible in the sense that it causes illness or distress. In general, it may be said that no physiological disturbances were noted either in the laboratory tests with individuals or in the tests made in a number of families.

Reports of the individual tests of the use of very young veal are as follows:

In family A the ages of the various members ranged from 4 to 65 years. Observations of the dietary value of bob veal were made at various times, using different portions of the carcass. With one exception no member of the family was apprised of the age of the veal, which was cut up into small pieces and prepared in the form of a stew. The criticism offered in regard to the meat was that it seemed somewhat dry, and one member of the family remarked that it seemed to be stringy. No one experienced any ill effects whatever from eating the meat, and all appeared to relish it as much as market veal.

Family B was comprised of comparatively young adults only. All the members of the family were apprised of the nature of the meat, which was served in the form of a roast. Their criticism of the veal was that it seemed rather tasteless—that is, lacked flavor—and that although it appeared good it would not be preferred to the ordinary market veal. No instances of any ill effects resulted from eating this meat.

Family C was composed of both children and adults whose ages ranged over a period of 50 or more years. In this study tests were made at two different times. On one occasion the veal was served in the form of a stew, while in the other case it was served roasted. Only one member

of the family knew the age of the veal. All appeared to enjoy the meat and made no remarks which would indicate that they were aware of its nature. No physiological disturbances were noted during these tests.

In general, it was noticed that when bob veal was cooked as a roast it presented a less appetizing appearance than did the more mature meats. This is due principally to the greater amount of water in the meat and to the less firm structure of the muscular tissue; consequently, when the meat is roasted or broiled—methods of cooking which cause the evaporation of considerable of the water—the meat shrinks away from the bones, producing an abnormal and undesirable appearance. However, if the veal is removed from the bone, it may be roasted, broiled, or used to make stews with very satisfactory results.

The younger veal was found to take the place quite satisfactorily of the common market veal. In practice, the shrinkage in cookery due to loss of water would mean the purchase of a larger quantity for the table if the same amount of meat is to be eaten. The deficiency in fat can be made up by adding fat in cookery. No study was made of the effects of handling upon market quality, or of the general question of legal regulation with respect to the marketing of young veal.

DIGESTION EXPERIMENTS

SELECTION AND COMPOSITION OF MATERIAL

The series of digestion experiments reported was made in this laboratory at the request of the Bureau of Animal Industry. The age of the calves used (in every case supplied by the Bureau of Animal Industry) was never more than five days, this age being arbitrarily selected in order to have as great a difference in maturity as possible between this type of veal and market veal. This was done so that any difference in the digestibility of the two types would be easier of detection should a difference exist. The calves used were procured without regard to breed or size and were healthy individuals passed by the Federal meat inspectors.

The calf was slaughtered the day preceding the cooking of the meat, and the carcass was stored in the meantime in a well-cooled refrigerator, no attempt being made, however, to study the keeping quality of the meat under ordinary trade and household conditions, a matter which apparently has not been studied. The cut most generally used in the digestion experiments was the leg, while the remainder was used for the dietary studies. This cut was chosen since it was easy to obtain the same cut of market veal for check experiments. The waste material (bone, tendon, etc.) in the legs of the very young veal was determined and found to be approximately 40 per cent. This amount of waste is much greater than that of mature veal, which is reported as 12 per cent (maximum, 25 per cent; 1, p. 31–32). Since muscular tissue is less developed in younger animals, it is logical to expect that there will be less tissue in proportion to bone.

In order to make a comparison of the percentages of the principal food constituents in the two types of uncooked meat, an analysis of the very young veal and market veal is given below. The percentages which are reported here are those obtained by averaging the results obtained from the analysis of a number of different samples. Very young veal: Water, 76.09 per cent; protein, 18.48 per cent; fat, 2.79 per cent; ash, 0.99 per cent. Market veal: Water, 71.97 per cent; protein, 20.07 per cent; fat, 7.43 per cent; ash, 1.28 per cent. A comparison of the two types of veal shows that very young veal contained more water than market veal and correspondingly less protein and fat. However, when the meat was cooked, the difference in the amount of protein and fat in the two types of veal was lessened, owing to the loss of more water from the very young veal than from the market veal. It was found that there was an average of 33.23 per cent of protein in the former and 34.41 per cent in the latter type of veal, although it is obvious that these figures represent merely the protein content of meat cooked by a single method. Obviously, if the meat were cooked in another way, for a longer or shorter period of time, using a different amount of fat, or employing more or less heat, the composition would vary quite materially. The chief difference in the composition of the meat from the very young and the older calves is in the percentage of water present; this decreases as the animal grows older, while at the same time the percentage of fat in the meat increases. Aside from this, the meat of the two ages shows very little difference.

NATURE OF THE DIET

The very young veal was prepared by cutting in a meat cutter all the meat to be used for an experimental period. The meat was then thoroughly mixed to give a uniform product for eating and for analysis. After the meat had been prepared in this manner, it was cooked in the form of small cakes resembling Hamburg steak. A small amount of animal fat was used in cooking, but no attempt was made to increase materially the fat content of the meat cakes, and, roughly, the same amount was used for both bob veal and mature veal.

It has often been observed that the digestibility of a food is more satisfactorily determined if it be incorporated in a mixed diet than if eaten singly. Consequently, it was decided that the basal ration to be used in studying the digestibility of the meat in question should contain fruit, bread and butter, and tea or coffee with sugar, if desired. It can readily be seen that this diet contains all the essential constituents of a well-balanced ration, while at the same time the protein constituent of the diet is derived principally from the veal. It was impossible in these tests to prevent the subjects from knowing the nature of the diet. For instance, they all knew that they were having meat of some sort and that fat was used for the purpose of frying,

but it is hardly possible that they were definitely aware of the source of the meat. If this was the case, it is reasonable to believe that the appetite of the subjects and the digestibility of the food were not affected by any psychic factor.

The three-day or nine-meal experimental period, which is very often used in investigations of this kind, was again adjudged to be most satisfactory. In order that the subjects should experience no monotony while eating the ration, each test period of three days per week was followed by a rest period of four days; and, furthermore, the digestion experiments were conducted only on alternate weeks. During the intervening weeks tests were made of the digestibility of other food materials.

SUBJECTS

Five subjects assisted in making this investigation. They were active young men of good physique and, as dental students, all were sufficiently interested in physiological questions to appreciate the importance of carrying out carefully such directions as were given them. They were urged to observe accuracy especially in the collection of feces, since in considering the digestibility of any food material it is more essential to know the amount of food retained and assimilated by the body than only the total amount of food consumed. To assist in identifying the feces of the test period, charcoal, which imparts a dark color to the feces, was given with the first meal of the test period and with the first meal following the period. The feces showing a dark color and all excreted until the dark color imparted by the charcoal was again noticed were retained for analytical purposes. The subjects were asked to bring notes describing their physical condition before, during, and after each test period. They all reported that with the exception of one or two colds they were in normal physical condition during the entire time that the investigation was in progress. Consequently, it has not been considered necessary to give in detail any of the individual reports which were received.

EXPERIMENTS WITH VERY YOUNG VEAL

Inasmuch as lean meat like very young veal consists almost wholly of water and protein, these experiments are concerned only with the digestibility of protein. One method of determining the digestibility of a single food of a mixed diet is to determine by digestion experiments with the basal ration alone the amount of undigested residue occurring from the accessory foods, and for which a corresponding correction may be applied to the digestibility of the total ration. A second method consists in estimating the digestibility of the basal ration. Since the digestibility of the protein of wheat flour, fruit, and butter have been accurately determined by previous investigators, satisfactory factors are available

for estimating the digestibility of the protein furnished by these foods. Accordingly, in this investigation it has been assumed that the protein of bread is 93.8 per cent (8, p. 33), that of butter 97 per cent (2, p. 104), and that of fruit 85 per cent (2, p. 104) available. The following equations illustrate the method of applying the above factors:

[Weight of protein in bread, butter, fruit]×[Percentage of undigested protein in each]=[Undigested protein from basal ration].

[Total undigested protein]−[Undigested protein from basal ration]=[Undigested protein from meat alone].

[(Meat protein consumed)−(Undigested protein from meat)]÷[Meat protein consumed]=[Estimated percentage digestibility of meat protein].

The results which have been obtained in the tests of the digestibility of very young veal are given in Table I:

Table I.—*Data of digestion experiments with very young veal in a simple mixed diet*

Item.	Weight.	Protein.	
	Gm.	*Gm.*	*Per cent.*
Experiment No. 5 (subject W. A. D.):			
Meat	736.0	227.4	30.90
Bread	707.0	67.9	9.61
Butter	254.0	2.5	1.00
Fruit	1,467.0	4.3	.29
Total food consumed	3,164.0	302.1	
Feces	41.0	15.6	38.07
Amount utilized		286.5	
Digestibility of entire ration			94.80
Estimated digestibility of very young veal			95.20
Experiment No. 6 (subject E. D. J.):			
Meat	704.0	217.5	30.90
Bread	942.0	90.7	9.63
Butter	207.0	2.1	1.00
Fruit	1,377.0	4.0	.29
Sugar	202.0		
Total food consumed	3,432.0	314.3	
Feces	65.0	28.8	44.31
Amount utilized		285.5	
Digestibility of entire ration			90.80
Estimated digestibility of very young veal			89.70
Experiment No. 16 (subject J. H. K.):			
Meat	703.0	287.6	40.01
Bread	745.0	66.5	8.03
Butter	154.0	1.5	1.00
Fruit	1,418.0	3.1	.22
Sugar	310.0		
Total food consumed	3,330.0	358.7	

TABLE I.—*Data of digestion experiments with very young veal in a simple mixed diet*—Continued

Item.	Weight.	Protein.	
	Gm.	*Gm.*	*Per cent.*
Experiment No. 16—Continued.			
Feces	45.0	21.6	48.53
Amount utilized		337.1	
Digestibility of entire ration			94.00
Estimated digestibility of very young veal			94.10
Experiment No. 17 (subject W. E. L.):			
Meat	706.0	289.1	40.95
Bread	816.0	72.8	8.92
Butter	129.0	1.3	1.00
Fruit	1,557.0	3.5	.22
Sugar	188.0		
Total food consumed	3,396.0	366.7	
Feces	44.0	18.9	42.94
Amount utilized		347.8	
Digestibility of entire ration			94.80
Estimated digestibility of very young veal			95.40
Experiment No. 27 (subject W. A. D.):			
Meat	699.0	202.3	28.94
Bread	859.0	76.8	8.94
Butter	133.0	1.3	1.00
Fruit	1,218.0	3.0	.25
Total food consumed	1,909.0	283.4	
Feces	56.0	11.4	20.37
Amount utilized		272.0	
Digestibility of entire ration			96.00
Estimated digestibility of very young veal			97.30
Experiment No. 28 (subject J. R. F.):			
Meat	752.0	217.6	28.94
Bread	717.0	64.1	8.94
Butter	206.0	2.1	1.00
Fruit	1,209.0	3.0	.25
Sugar	68.0		
Total food consumed	2,952.0	286.8	
Feces	58.0	23.3	40.22
Amount utilized		263.5	
Digestibility of entire ration			91.90
Estimated digestibility of very young veal			91.40
Experiment No. 29 (subject W. E. L.):			
Meat	684.0	197.9	28.94
Bread	683.0	61.1	8.94
Butter	127.0	1.3	1.00
Fruit	1,280.0	3.2	.25
Sugar	115.0		
Total food consumed	2,066.0	263.5	

TABLE I.—*Data of digestion experiments with very young veal in a simple mixed diet*—Continued

Item.	Weight.	Protein.	
	Gm.	*Gm.*	*Per cent.*
Experiment No. 29—Continued.			
Feces	68.0	32.5	47.82
Amount utilized		231.0	
Digestibility of entire ration			87.70
Estimated digestibility of very young veal			85.80
Average food consumed per subject per day	964.2	103.6	

SUMMARY OF EXPERIMENTS WITH VERY YOUNG VEAL

Experiment No.	Subject.	Digestibility of protein. Total diet.	Veal alone.
		Per cent.	*Per cent.*
5	W. A. D	94.8	95.3
6	E. D. J	90.8	89.7
16	J. H. K	94.0	94.1
17	W. E. L	94.8	95.4
27	W. A. D	96.0	97.3
28	J. R. F	91.9	91.4
29	W. E. L	87.7	85.8
	Average	92.9	92.7

From the data recorded in these tables it may be calculated that an average of 237 gm. of meat, furnishing 78 gm. of protein, or 75 per cent of the total protein of the diet, was eaten daily. The five subjects completed the experiments in good condition and without having experienced any physiological disturbances. The average values of seven experiments for the digestibility of total protein and that of meat protein alone are practically identical, being for the former 92.9 per cent and for the latter 92.7 per cent. The values estimated for the digestibility of bob-veal protein in the different experiments are not consistently higher or lower than the determined values for the protein of the total diet. This irregularity is very likely due to the variation in the amounts of protein obtained from the different sources.

CHECK EXPERIMENTS

Tests of the digestibility of market veal, using the same basal ration and with the same subjects and method of cooking as for bob veal, were made in order to compare the digestibility of very young and market veal under identical conditions. For this purpose legs of veal from animals at least 4 weeks old were purchased in the open market. Although it was realized that market veal contained a larger percentage

of fat than bob veal, only the superficial fat was removed before cooking, no attempt being made to secure meat cakes from market veal of the same composition as those made of bob veal. The fat contained in the market veal comprised the minor portion of the total fat content of the diet, and, moreover, for the sake of comparison with bob veal, it was necessary to know only the digestibility of protein. The digestibility of the protein alone, therefore, has been studied in these experiments. This is reported for the entire ration and has been estimated for the protein of meat alone in the manner previously described.

The results of three experiments with three subjects are given in Table II.

TABLE II.—*Data of digestion experiments with market veal in a simple mixed diet*

Item.	Weight.	Protein.	
Experiment No. 18 (subject J. H. K.):	*Gm.*	*Gm.*	*Per cent.*
Meat	629.0	219.0	34.81
Bread	569.0	53.0	9.31
Butter	178.0	1.8	1.00
Fruit	1,568.0	3.0	0.19
Total food consumed	2,944.0	276.8	
Feces	38.0	17.1	45.00
Amount utilized		259.7	
Digestibility of entire ration			93.80
Estimated digestibility of market veal			93.90
Experiment No. 19 (subject W. E. L.):			
Meat	689.0	239.8	34.81
Bread	725.0	67.5	9.31
Butter	158.0	1.6	1.00
Fruit	1,536.0	2.9	0.19
Sugar	156.0		
Total food consumed	3,264.0	311.8	
Feces	57.0	24.8	43.5
Amount utilized		287.0	
Digestibility of entire ration			92.00
Estimated digestibility of market veal			91.60
Experiment No. 22 (subject W. A. D.):			
Meat	653.0	277.9	42.56
Bread	801.0	59.6	7.44
Butter	92.0	0.9	1.00
Fruit	1,702.0	4.3	0.25
Total food consumed	3,248.0	342.7	
Feces	62.0	24.1	38.04
Amount utilized		318.6	
Digestibility of entire ration			93.00
Estimated digestibility of market veal			92.90
Average food consumed per subject per day	1,050.7	103.4	

SUMMARY OF EXPERIMENTS WITH MARKET VEAL

Experiment No.	Subject.	Digestibility of protein.	
		Total diet.	Market veal alone.
		Per cent.	*Per cent.*
18	J. H. K.	93.8	93.9
19	W. E. L.	92.0	91.6
22	W. A. D.	93.0	92.9
	Average	92.9	92.8

The digestibility of the protein of the total diet was determined to be 92.9 per cent, while it was estimated that the protein of market veal alone was 92.8 per cent available, values somewhat lower than those found by Grindley (7) for roast veal and for meat in general. The amounts of food eaten in these experiments and those with bob veal were approximately the same and furnished the same average amount of total protein (103 gm. per day), indicating that both rations were eaten with equal relish.

CONCLUSIONS

As determined by the experiments herein reported, the digestibility of the protein of bob veal is the same as that found for market veal—namely, 93 per cent, in round numbers. The subjects of both dietary and digestion experiments, so far as could be learned, experienced no physiological disturbances during the experimental period or afterwards. The tests showed that such veal can be prepared for the table in palatable ways and that so far as could be judged it was not unwholesome when eaten in quantity. In the digestion experiments the average weight of protein supplied by the meat exceeded that generally furnished by the meat portion of the ordinary diet, indicating that very young or bob veal was not distasteful. The experiments here reported also indicate that the general opinion that young veal is a common cause of digestive disturbance or fails to digest as thoroughly as similar foods is not justified.

LITERATURE CITED

(1) Atwater, W. O., and Bryant, A. P.

1899. The chemical composition of American food materials. U. S. Dept. Agr. Office Exp. Stas. Bul. 28 (rev. ed.), 87 p., 4 fig.

(2) ——— ———

1900. The availability and fuel value of food materials. *In* Conn. Storrs Agr. Exp. Sta. 12th Ann. Rpt. 1899, p. 73–110.

(3) Berg, W. N.

1916. Biochemical comparisons between mature beef and immature veal. *In* Jour. Agr. Research, v. 5, no. 15, p. 667–711, 6 fig. Literature cited, p. 708–711.

(4) Fish, P. A.
1911. Preliminary observations on bob veal. *In* Rpt. N. Y. State Vet. Col. 1909/10, p. 130–145.

(5) ———
1912. Further observations on bob veal. *In* Rpt. N. Y. State Vet. Col. 1910/11, p. 138–151, 4 pl.

(6) ———
1914. The digestibility and decomposability of bob veal. *In* Rpt. N. Y. State Vet. Col. 1912/13, p. 51–81, 17 pl.

(7) Grindley, H. S., Mojonnier, Timothy, and Porter, H. C.
1907. Studies of the effect of different methods of cooking upon the thoroughness and ease of digestion of meat at the University of Illinois. U. S. Dept. Agr. Office Exp. Stas. Bul. 193, 100 p.

(8) Woods, C. D., and Merrill, B. H.
1904. Studies on the digestibility and nutritive value of bread at the Maine agricultural experiment station, 1899–1903. U. S. Dept. Agr. Office Exp. Stas. Bul. 143, 77 p.

INFLUENCE OF CALCIUM AND MAGNESIUM COMPOUNDS ON PLANT GROWTH[1]

By F. A. Wyatt,[2]

Assistant in Soil Fertility, Agricultural Experiment Station of the University of Illinois

INTRODUCTION

Some investigators seem to question the advisability of using magnesium-bearing minerals in agricultural practices, since they deem magnesium detrimental to optimum plant growth. Magnesium in some forms is detrimental to plant growth. However, the natural carbonates, such as limestones and dolomites, are not detrimental but in reality beneficial to plant growth when applied in amounts sufficient to neutralize soil acidity. Plants were found to grow and mature normally in pure dolomite and limestone.

In scientific circles considerable attention has been paid to the theory that calcium and magnesium must occur in a definite ratio for the optimum production of crops. Loew claims to have proposed this theory in 1892 (15)[3], and much work has been conducted along this line, especially during the last decade. From the data presented in the following pages it will be seen that the ratio, within wide limits, had no effects.

The presence of sufficient quantities of calcium and magnesium in all soils is essential for the profitable production of crops. Various forms and quantities of these two elements may largely control the yields and composition of the harvests.

It is a well-known fact that plants will tolerate larger amounts of an essential element than they require. The quantity of calcium and magnesium taken up by plants is dependent upon the amount available and upon the kind of plants. The silicates of calcium and magnesium are relatively insoluble, while the chlorids are very soluble. Dolomite is denser and less soluble than limestone but more soluble than magnesite. Synthetic compounds of magnesium are more soluble, however, than similar compounds of calcium.

Alfalfa, when grown in sand and soil cultures with varying amounts of calcium and magnesium minerals, such as dolomite and magnesite, also with prepared compounds of these two elements, such as the chlorids, sulphates, and carbonates, was found to contain varying amounts of

[1] This paper was submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Agronomy in the Graduate School of The University of Illinois in 1915.

[2] It is with pleasure that I acknowledge my indebtedness to Prof. C. G. Hopkins, Dr. A. L. Whiting, and Prof. J. H. Pettit for suggestions and helpful criticisms.

[3] Bibliographic citations in parentheses refer to "Literature cited," p. 616–619.

calcium and magnesium. Some treatments showed as much as 52.5 pounds of calcium and 12.98 pounds of magnesium per ton of dry alfalfa. However, the above amounts were in excess of the absolute requirements, as smaller applications gave as large yields and the alfalfa contained only 28 pounds of calcium and 8 pounds of magnesium per ton of dry matter. On this basis 6 tons of alfalfa with a high-calcium content would contain 315 pounds of calcium and 77.88 pounds of magnesium, or the equivalent of 787.5 pounds of calcium carbonate and 272.5 pounds of magnesium carbonate. Wheat straw, when grown in pure dolomite, contained 14.48 pounds of calcium and 14.6 pounds of magnesium per ton, whereas when grown in the absence of excessive amounts of these two elements the straw contained only 5.96 pounds of calcium and 5.43 pounds of magnesium per ton.

REVIEW OF THE LITERATURE

Solution cultures and pot cultures have contributed largely to our present knowledge of plant nutrition. Woodward (42) found that the solid particles of the soil furnished nourishment to the growing plants and that water acted only as a carrier.

Wolf (4) found by using beans and maize in controlled solutions, that the concentration as well as the kind of salts in the solution effected plant growth. His results show that when the concentration of the external solution was more than 0.25 per cent it became the controlling factor; whereas if less than 0.25 per cent absorption was controlled by the solution within the roots.

Dassonville (1) found that cutinization and lignification of the epidermis of leaves occurred much more rapidly in distilled water than in nutrient solutions; also that the growth of hemp and buckwheat was not influenced by the presence or absence or calcium and magnesium.

The crop is the measure of the resultant of all factors. In accordance with the present knowledge any one or many of the factors can be controlled. Likewise, the total amounts of the elements essential for crop production can be quantitatively determined.

Magnesium is essential for the growth of any living cell. Calcium is likewise essential except for the lower fungi and lower algæ, which alone are able to exist without it. Loew (16, p. 44) shows that neutral oxalates are not poisonous to the lower fungi. He attributes the deleterious effects in higher plants to the change in the structure of the calcium-protein compounds, due to the formation of calcium oxalate, while the disturbance is brought about by the change in imbibition caused by the formation of potassium-protein compounds, and that magnesium may bring about this change provided there is a deficiency in calcium.

Reed (29) found calcium to be necessary to the activity and growth of chlorophyll-containing organs. Willstätter (40) has pursued in detail

the study of chlorophyll and finds it to be a magnesium compound with generally three times as much green pigment as yellow pigment. He found that the magnesium content of chlorophyll was constant in both land and sea plants; therefore, it must function other than as a catalyzer. Pfeffer (27, p. 425), Macdougall (17, p. 219), Peirce (26, p. 100) and others believe magnesium and calcium play an important and necessary function in plant synthesis and cell formation, but are unable to assign any specific rôle to either of these elements.

There has been considerable contention as to whether calcium could be replaced by other members of the group. Haselhoff (7) grew beans and maize in solutions containing varying quantities of calcium and strontium and concluded that strontium seemed to take the place of calcium, replacing it only when the supply of calcium was inadequate. But it must be remembered that he first used calcium and strontium together in the solution and later reduced the calcium. However, Loew (16, p. 48) was unable to substantiate these results when he used species of Tradescantia.

Loew explains the toxicity between calcium and magnesium as being due to the formation of an insoluble condition of the phosphoric acid being fixed by the calcium, and that the framework (15) of the nucleus and plastids is a double organic salt of calcium and magnesium. However, Meurer (19) and Nathansohn (23) offer another explanation: Cells being selective in their absorption of ions can check osmosis before a balance is reached between the solution within and without the cell, and the absorption of salts does not increase proportionally with the increase of concentration of the outside solution. Osterhout (24) using calcium nitrate and magnesium nitrate was unable to substantiate Loew's assertion.

Considerable work has been done upon the antagonism of respective salts for each other in solution. Kearney (11, p. 20) shows that calcium salts are most beneficial in reducing toxicity. Lipman (14) reports toxicity between magnesium and sodium but not between magnesium and calcium.

Numerous investigators have sought answers to the proposed theory of a lime-magnesia ratio with just as numerous and conflicting results. Solutions, pot cultures of soil and sand, and field soils have all been employed in attempts to settle the controversy. Ulbricht (34) showed that yellow lupines, barley, and vetch were injured by applications of lime, especially when it contained high percentages of magnesia. Magnesia apparently increased the proportional yield of grain in the case of barley and lupines. Dojarenko (2), however, concluded that the theory of a definite calcium-magnesium ratio was not tenable, as many Russian soils containing great excesses of calcium over magnesium were benefited by liming.

The results of water and soil cultures by Gössel (6) failed to substantiate the theory of a definite ratio of calcium to magnesium. He obtained the highest yields for beans and barley with water cultures when the ratio of lime to magnesia was 0.04 to 1, and concluded that the effect of liming is dependent upon the character of the soil and not upon a definite ratio of lime to magnesia. About this same time the Japanese investigators (22) were actively engaged with the problem. However, their results all seem to bear out the theory of a definite ratio.

Konovalov (12), a Russian investigator, reports studies with barley, millet, oats, and maize, varying the ratio of calcium oxid to magnesium oxid, as follows: 13.4 to 1, 6.7 to 1, 3.3 to 1, 0.8 to 1, and 0.4 to 1. He found that the yields tended to increase with the increase of lime application, provided the magnesia content remained constant. Notwithstanding these results, Voelcker (35, 36, 37) states that the ratio is best at 1 to 1.

Meyer (20, 21) found that with buckwheat and oats the dependence of maximum yields on a definite ratio of calcium to magnesium could not be proved even in the case of soils containing more calcium than magnesium or vice versa. Undoubtedly the most extensive investigations regarding a definite calcium-magnesium ratio have been conducted by Lemmerman (13) et al. They used six different soils and grew vetch, oats, barley, rye, wheat, clover, mustard, and buckwheat, with the investigations extending over three years, 1907 to 1909, inclusive. From the standpoint of yields the ratio had no effects within wide limits. Stewart (33) reports soils having 16.88 per cent of calcium oxid and 6.1 per cent of magnesium oxid which were cropped for 40 years without the addition of fertilizers, except in the case of sugar beets, which received manure. The 8-year average yields are 80 bushels for oats, 50.4 bushels for wheat, 262.3 bushels for potatoes, and 21.8 tons for sugar beets.

Wartiadi (38) used sand and water cultures with wheat and barley and found that calcium and magnesium were beneficial or detrimental in proportion to their relative amounts in the culture solution. Russell (30, p. 144) finds no connection between the lime-magnesia ratio and the productivity of the soil. Haselhoff (8) also failed to substantiate Loew's theory, while Hopkins (9, pp. 170–171) found magnesium carbonate beneficial up to 0.8 per cent when added alone and in connection with calcium sulphate in such amounts as to maintain a ratio of 4 to 7, respectively, of magnesium oxid and calcium oxid.

Gile (3) reports that with the chlorids of calcium and magnesium at low concentrations the ratio exerted no influence, while at high concentrations it was effective. Good yields of pineapples (4) were produced from soils in Porto Rico when the ratio varied between 1 to 13 and 73 to 1; and in one field where the ratio of calcium oxid to magnesium oxid was 1,461 to 1 a yield of 60 tons of sugar cane was realized.

Pisciotta (28), an Italian investigator, reports the analysis of 60 soils which show a wide variation in the lime-magnesia ratio, due to the variation in the lime content. Patterson (25) found that magnesian lime, which is claimed to be poisonous, gave the highest yields.

In summing up the literature studies previously mentioned, it will be seen that Loew and his associates and Japanese students maintain the theory of a definite lime-magnesia ratio, as do Ulbricht and Wartiadi, whereas Dojarenko, Gössel, Konovalov, Meyer, Lemmerman, Haselhoff, Gile, and Patterson claim that a definite ration of lime to magnesia is not tenable and, furthermore, lacks substantiation.

Lemmerman et al. have undoubtedly conducted the most extensive investigations upon this subject and conclude that there is no correlation between maximum crop productions and the ratio of lime to magnesia. Soils reported by Russell and by Gile show wide variations in the lime-magnesia ratio, also in the percentages of these two elements, and that there fails to be any correlation between the productivity of a soil and its ratio of lime to magnesia.

Solution cultures show that a specific ratio of lime to magnesia is not equally effective in dilute solutions and in concentrated solutions. This indicates that the effectiveness is dependent upon the total balance of all the salts in solution instead of merely the ratio of calcium to magnesium.

The preponderance of evidence appears to be against a definite ratio of lime to magnesia, especially with respect to soil cultures in pots and under field conditions. What really seems of first magnitude is the resultant of all factors—that is, the climate, the plant, and structure, reaction, micro-organic activity, and composition of the soil.

EXPERIMENTAL WORK

These experiments were planned with the idea of studying the effects of calcium and magnesium upon plant growth when applied in different natural and in artificially prepared forms. Studies were made to determine the amount of calcium and magnesium which the plants could tolerate. The relation between the ratios of these two elements in the plants, in the soils, and in the materials applied was also studied.

Dolomite, limestone, magnesite, calcareous soils, and brown silt loam were used as sources of the natural forms, while prepared materials, such as the carbonates, chlorids, and sulphates, served as sources of the artificial forms. Increasing amounts of the various forms were used, also a variance in the ratio of calcium to magnesium was employed. The earlier applications varied from 0.1 to 0.6 per cent of magnesium added in magnesium carbonate and in magnesite. Later the following amounts were employed: 2, 6, and 10 per cent of magnesium in magnesite; 10 and 12.7 per cent of magnesium in dolomite; 0.1, 0.01, and 0.001 per cent of magnesium in the carbonates, chlorids, and sulphates. In each series sand or soil was used as a control.

DESCRIPTION OF PROCEDURE AND METHODS

Earthen pots 6.5 inches in diameter by 7.5 inches in depth were used. Each pot contained 13.2 pounds of sand, while in the soil series each contained 8.8 pounds of brown silt loam. Sand and soil were used as mediums of control, and to these two materials were added the various forms and amounts of calcium and magnesium.

Various methods were pursued in extracting the sand. At first dilute hydrochloric acid (HCl) was kept in contact with the sand for 48 hours, but this failed to remove all the calcium and magnesium. Later the sand was extracted with stronger acid (1,350 c. c. of concentrated hydrochloric acid plus 1,000 c. c. of distilled water) for periods of from 9 to 14 days. Sand was also digested on a steam bath for 4 days with this same strength acid. None of the above processes were able to remove all the calcium and magnesium from the sand, as will be seen from the analysis reported.

At intervals varying from 10 days to 2 weeks plant food was added from the following solutions:

(1) Potassium sulphate, 50 gm. to 2½ liters of water; (2) ammonium nitrate, 80 gm. to 2½ liters of water; (3) disodium phosphate, 26.1 gm. to 2½ liters of water; (4) ferric chlorid, 0.4 gm. to 1 liter of water.

The calcium and magnesium were applied in forms previously mentioned. The moisture content of the sand was at first 12 per cent, but it was later raised to 14 per cent, while for the brown silt loam it was 24 per cent. Every 10 days the pots were brought to standard weight by adding distilled water.

All crops were grown in the agronomy greenhouses at the University of Illinois. The principal crops used in these studies were wheat (*Triticum* spp.), alfalfa (*Medicago sativa*), soybeans (*Soja max*), and cowpeas (*Vigna sinensis*). Oats (*Avena sativa*), clover (*Trifolium pratense*), timothy (*Phleum pratense*), and sweet clover (*Melilotus alba*) were also used to test the effect of artificial carbonates upon germination.

In the wheat and soybean series, 10 seeds per pot were planted and 7 plants permitted to grow, while for alfalfa 15 plants were permitted to grow whenever possible.

In making determinations for calcium and magnesium, the soils were first fused with sodium peroxid and from this point the usual method was employed. The calcium oxalate was dissolved in dilute sulphuric acid (H_2SO_4) and the calcium calculated from the amount of *N/10* potassium permanganate required to oxidize the oxalic acid thus formed. The magnesium was precipitated as magnesium-ammonium phosphate and burned to the pyrophosphate. In analyzing the plants 2 gm. of finely ground material were ashed, taken up in hydrochloric acid, and the calcium and magnesium determined as above stated. Acid extractions of the dolomites and limestones proved as good as fusions.

TABLE I.—*Composition of materials supplying calcium and magnesium to the soil*

Material.	Calcium carbonate.	Magnesium carbonate.	Calcium.	Magnesium.	Molecular ratio of calcium to magnesium.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	
Dolomite C1	43.65	35.26			5:4.8
Dolomite C3	51.18	44.9			5:5.2
Magnesite C4		98.37			
Limestone [1]	84.2	5.85			
Brown silt loam			0.305	0.35	5:9.6
Calcareous soil			5.58	2.64	5:3.8
Sand extracted with dilute hydrochloric acid for 48 hours			.0142	.016	
Sand extracted with concentrated hydrochloric acid for four days on a steam bath			.0128	.0089	
Sand not extracted			.017	.0148	

[1] From Columbia, Ill.

The brown silt loam used in series C and D was taken from the surface of sod land and had only the coarser roots removed. The calcareous soil was taken from a layer varying from 8 to 12 inches in thickness and 72 inches below the surface in the forestry near plot 719 of the north farm of the university. The coarser pebbles were removed before using. The analysis in Table I refers to the portion used in growing crops; the coarser pebbles show a higher content of calcium and magnesium, or 13.34 per cent of calcium and 5.97 per cent of magnesium.

The 6,000 gm. of sand, after being extracted with hydrochloric acid, contained for each pot from 768 to 852 mgm. of calcium and from 540 to 960 mgm. of magnesium. From the following tables it will be seen that the plants had the power to obtain considerable quantities of the apparently insoluble calcium and magnesium silicate, as they obtained quantities in excess of the amount added in the seeds, although they show lower contents than plants grown in an excess of these materials. The chemically pure magnesium carbonate gave an immediate alkaline reaction to phenolphthalein upon the addition of distilled water. Dolomites C1 and C3 likewise showed an alkaline reaction to this indicator, but only after having been in distilled water over night. Magnesite after standing in distilled water from 8 to 12 hours was alkaline to phenolphthalein, as was also the calcareous soil.

In experimenting with artificially prepared magnesium carbonate, a great deal of care was taken to obtain the alkali-free substance to begin with. This can be prepared by a precipitation from solution with ammonium carbonate. Magnesium carbonate in the presence of water has a great tendency to hydrolyze, which may at least partially explain its poisonous effect.

EFFECT OF MAGNESIUM AND CALCIUM IN PREPARED CARBONATES AND IN DOLOMITE UPON WHEAT AND ALFALFA GROWN IN SAND (SERIES A AND B)

The sand used in series A and B was extracted as previously described, washed free from acid, and the application made on the moisture-free basis. Pots 1 and 2 of series A and pots 21 and 22 of series B received no calcium or magnesium. Pots 3 and 4 of series A and pots 23 and 24 of series B received 2 per cent of dolomite C1 or 0.2 per cent of the element magnesium. Pots 9 to 20, inclusive, of series A and pots 29 to 40, inclusive, of series B received magnesium and calcium in prepared carbonate in amounts varying from 0.1 per cent to 0.6 per cent of magnesium. The magnesium carbonate was alkaline and of the following formula: $Mg(OH)_2.4MgCO_3$.

Table II contains the yields for the above treatments. When added to sand, the lowest applications of magnesium in the prepared carbonate very materially retarded germination and inhibited growth; whereas amounts of 0.6 per cent of magnesium in dolomite caused no injury and even benefited growth.

The ratio of calcium to magnesium throughout this and all succeeding tables is reported as molecular calcium to molecular magnesium, with calcium always expressed as 5. The yields and percentages in all the tables are reported on the water-free basis. The wheat, series A, was harvested 83 days after being planted, while the alfalfa, series B, was harvested 84 days after being planted.

TABLE II.—*Yields of wheat and alfalfa (in grams per pot on a water-free basis) in sand—series A and B*

Treatment.	Molecular ratio of calcium to magnesium.	Wheat, series A.			Alfalfa, series B.		
		Pot No.	Tops.	Roots.	Pot No.	Tops.	Roots.
None	....	1	20.9	22.2	21	5.16	6.42
None	....	2	18.5	23.2	22	3.12	[illegible]
Percentage of magnesium in dolomite C1:							
0.2	5:4.8	3	7.07	5.4	23	6.24	[illegible]
.2	5:4.8	4	23.0	18.8	24	7.84	12.47
.4	5:4.8	5	23.0	15.0	25	5.97	[illegible]
.4	5:4.8	6	17.8	10.0	26	5.61	[illegible]
.6	5:4.8	7	20.7	12.9	27	7.75	[illegible]
.6	5:4.8	8	10.8	6.3	28	7.21	[illegible]

The pots receiving magnesium and calcium in the prepared carbonates in a ratio of calcium to magnesium, as 5 to 4, inhibited germination and permitted no growth.

Table III shows the analysis of the plants reported in Table II. The results here reported are the average of four determinations from duplicate pots.

From Table III it can be seen that the alfalfa is a heavier feeder on calcium and magnesium than is wheat, and that the percentages and the total amounts removed by the plants tend to increase with the increase in application, except where the calcium and magnesium are applied in the artificially prepared carbonates, in which case the lowest application is sufficient to inhibit growth and retard germination.

Throughout all the series the general tendency was for the calcium and magnesium content of the plants to increase with the increase in application. Wheeler (39) found that when magnesium was applied in the form of the sulphate the crop showed the ratio of magnesium oxid to calcium oxid to be as 1 to 1.13, but when magnesium was not present in the fertilizer the ratio of magnesium oxid to calcium oxid was 1 to 2.7.

TABLE III.—*Analyses of wheat and alfalfa—series A and B*

Pot No.	Substance added. Calcium.	Substance added. Magnesium.	Composition of plants. Calcium.		Composition of plants. Magnesium.		Molecular ratio of calcium to magnesium.
	Per cent.	*Per cent.*	*Mgm.*	*Per cent.*	*Mgm.*	*Per cent.*	
WHEAT STRAW							
1 and 2 [a]	0.0142	0.0165	37.0	0.187	21.4	0.108	5:5.1
3	.333	.2	68.5	.298	62.6	.271	5:7.6
7 and 8	.999	.6	60.1	.386	66.6	.421	5:9.1
WHEAT ROOTS							
1 and 2	.0142	.0165	43.4	.187	24.8	.09	5:4.1
3	.333	.2	85.3	.452	55.3	.292	5:5.4
7 and 8	.999	.6	91.8	.96	47.9	.50	5:4.35
ALFALFA HAY							
21 and 22 [a]	.0142	.0165	14.4	.347	6.84	.164	5:3.9
23 and 24	.333	.2	181.0	2.565	30.6	.431	5:1.4
27 and 28	.999	.6	196.5	2.622	48.6	.649	5:2
ALFALFA ROOTS							
21 and 22	.0142	.0165	8.52	.19	6.26	.14	5:6.1
23 and 24	.333	.2	48.8	.46	50.0	.472	5:8.5
27 and 28	.999	.6	54.4	.561	78.9	.815	5:12

[a] Pots 1, 2, 21, and 22 were extracted sand and received no calcium and magnesium.

EFFECTS OF CALCIUM AND MAGNESIUM IN PREPARED CARBONATES AND IN DOLOMITE UPON WHEAT AND ALFALFA IN BROWN SILT LOAM (SERIES C AND D)

Magnesium and calcium in prepared carbonates were less harmful in brown silt loam than in sand (series C and D). In fact, applications of 0.1 per cent of magnesium or 0.35 per cent of magnesium carbonate gave an increase over the check, and 0.7 per cent of the carbonate was practically as good. It must be remembered that the soil before treatment contained 0.305 per cent of calcium and 0.352 per cent of magnesium. The calcium and magnesium were added in the relation of 5 to 4, but the amounts in the soil changed this ratio to 5 to 7.1. Applications of 3.5 tons of prepared magnesium carbonate per acre were beneficial, 7 tons were about equal to the check, while upward of 10 tons caused practically no growth of the plants.

TABLE IV.—*Yields of wheat and alfalfa (in grams per pot on a water-free basis) in brown silt loam—series C and D*

Treatment.	Molecular ratio of calcium to magnesium.	Wheat, series C.			Alfalfa, series D.		
		Pot No.	Tops.	Roots.	Pot No.	Tops.	Roots.
Brown silt loam only	5:9.6	41	8.9	6.8	65	4.64	6.86
Do	5:9.6	42	9.3	7.9	66	4.28	6.53
Percentage of magnesium in magnesium carbonate plus calcium carbonate:							
0.1	5:7.1	43	11.6	7.16	67	5.96	6.95
	5:7.1	44	11.0	7.0	68	5.35	6.5
.2	5:7.1	45	8.1	5.55	69	2.58	2.49
	5:7.1	46	8.1	6.07	70	3.03	2.85
.3	5:7.1	47	1.45	1.81	71	.09	.....
	5:7.1	48	4.08	3.17	72	2.58	1.69
.4	5:7.1	49	.9	.72	73	.....	.....
	5:7.1	50	.18	.18	74	.....	.....
.5	5:7.1	51	1.85	2.35	75	.....	.....
	5:7.1	52	.09	.09	76	.....	.....
.6	5:7.1	53	.09	.09	77	.....	.....
	5:7.1	54	.09	.....	78	.....	.....
Percentage of magnesium in dolomite C1:							
0.2	5:4.8	55	9.52	5.45	79	5.17	6.05
	5:4.8	56	10.5	6.07	80	5.0	5.08
.4	5:4.8	57	9.61	8.15	81	5.35	6.85
	5:4.8	58	9.07	7.25	82	5.08	5.88
.6	5:4.8	59	10.0	8.8	83	4.37	3.74
	5:4.8	60	9.52	8.15	84	5.43	6.15
2	5:4.8	61	8.9	4.53	85	5.43	4.72
	5:4.8	62	5.71	4.62	86	5.60	4.64
4	5:4.8	63	6.07	4.53	87	5.17	5.08
	5:4.8	64	7.52	4.53	88	5.52	3.65

MacIntire (18), while working with three different kinds of soils, found that 8 tons per acre of precipitated magnesium carbonate were decidedly toxic to wheat. He also found that both the oxids and the carbonates of precipitated magnesium were many times more soluble than the corresponding forms of calcium, while in the case of the native mineral

carbonates limestone was 1.62 times as soluble as dolomite and more than 3 times as soluble as magnesite.

Applications of dolomite C1 up to 40 per cent caused no injury to either wheat or alfalfa.

Table IV shows the treatments and yields of series C and D. Analyses of these plants are reported in Table V. Series C (wheat) was harvested 83 days after planting and series D (alfalfa) was harvested 84 days after planting.

From Table V it can be seen that wheat grown in soil (pots 41 and 42) shows 0.279 per cent of calcium and 0.256 per cent of magnesium, but when grown in extracted sand (Table III, pots 1 and 2) it had only 0.187 per cent of calcium and 0.108 per cent of magnesium, showing that there is a decided tolerance for these two elements. By comparing the wheat with the alfalfa it can be seen that, while alfalfa is a heavier feeder than wheat on calcium and magnesium, the proportional amounts of calcium are greater in alfalfa than in wheat.

TABLE V.—*Analysis of wheat and alfalfa grown in brown silt loam—series C and D*

WHEAT STRAW

Pot No.	Substance added.		Composition of plants.				
	Calcium.	Magnesium.	Calcium.		Magnesium.		Molecular ratio of calcium to magnesium.
	Per cent.	*Per cent.*	*Mgm.*	*Per cent.*	*Mgm.*	*Per cent.*	
41 and 42	0.305	0.352	27.1	0.297	23.31	0.256	5:7.2
43 and 44	.527	.458	33.6	.297	52.7	.467	5:13.1
47 and 48	.971	.671	9.76	.352	32.8	1.19	5:28.1
55 and 56	.315	.2	35.4	.353	33.8	.337	5:7.9
63 and 64	6.30	4.0	29.2	.43	31.0	.456	5 8.8

WHEAT ROOTS

41 and 42	.305	.352	21.9	.298	19.6	.266	5:7.5
43 and 44	.527	.458	29.8	.419	25.1	.352	5:7
47 and 48	.971	.671	9.7	.352	15.5	.626	5:14.1
55 and 56	.315	.2	34.0	.53	22.8	.397	5:6
63 and 64	6.3	4.0	50.0	1.102	34.1	.752	5:5.7

ALFALFA HAY

65 and 66	.305	.352	71.0	1.595	17.7	.398	5:2.2
67 and 68	.527	.458	78.4	1.56	35.3	.624	5:3.8
71 and 72	.971	.671	11.4	.86	12.82	.96	5:9.3
79 and 80	.315	.2	85.5	1.684	25.0	.492	5:2.4
87 and 88	6.30	4.0	98.5	1.84	27.8	.521	5:2.3

ALFALFA ROOTS

65 and 66	.305	.352	21.46	.326	34.0	.462	5:11.8
67 and 68	.527	.458	21.2	.314	37.5	.558	5:14.7
71 and 72	.971	.671	10.64	.628	17.2	1.00	5:13.3
79 and 80	.315	.2	25.0	.449	30.0	.54	5:10
87 and 88	6.30	4.0	96.0	2.2	59.2	1.358	5:5.1

EFFECT OF MAGNESIUM AND CALCIUM IN DOLOMITE, MAGNESITE, AND PREPARED CARBONATES UPON WHEAT AND ALFALFA IN SAND (SERIES E AND F)

Table VI shows the yields of wheat and alfalfa when grown in sand and treated with increasing amounts of magnesium in magnesite. The applications vary between 0.1 per cent of magnesium and 0.6 per cent of magnesium or 0.35 to 2.1 per cent of megnesite. Chemically pure calcium carbonate was added to make a ratio of calcium to magnesium equal to 5 to 4. The wheat and alfalfa in these two series were grown to maturity, the seeds being ground up with the straw and an analysis of the composite made.

There was but little seed upon the alfalfa, owing to the fact that it was grown under screens and the fertilization was poor. However, the treatments seemed to cause no injury except where magnesium was applied in the form of the prepared carbonates in pots 104 and 120.

TABLE VI.—*Yields of wheat and alfalfa (in grams per pot on a water-free basis) in magnesite—series E and F*

Treatment.	Molecular ratio of calcium to magnesium.	Wheat, series E.		Alfalfa, series F.			
		Pot No.	Tops.	Pot No.	First crop, tops.	Second crop, tops.	Roots.
None	....	89	7.25	105	6.86	5.2	3.78
Percentage of magnesium in magnesite plus calcium carbonate:							
0.1	5:4	90	6.53	105	6.00	5.36	7.13
	5:4	91	7.16	107	8.35	5.8	5.46
.2	5:4	92	5.98	108	6.77	6.16	7.48
	5:4	93	9.88	109	6.25	4.94	4.57
.3	5:4	94	10.96	110	5.72	5.2	3.96
	5:4	95	6.8	111	5.9	5.1	4.32
.4	5:4	96	7.07	112	5.64	4.48	4.48
	5:4	97	7.8	113	6.77	5.02	1.85
.5	5:4	98	9.15	114	6.07	4.31	1.40
	5:4	99	7.8	115	7.92	4.4	2.38
.6	5:4	100	11.4	116	7.48	5.2	5.02
	5:4	101	6.25	117	7.32	5.55	3.52
Percentage of magnesium in dolomite C_3:							
0.6	5:5.2	102	9.42	118	6.34	5.9	4.93
	5:5.2	103	10.86	119	5.72	4.66	2.64
Percentage of magnesium in magnesium carbonate	5:4	104	....	120	......	......	......

Table VII shows that the higher treatments have higher contents of calcium and magnesium in the plants. The wheat grown in sand (pot 89) shows only 3.3 pounds of calcium and 2.6 pounds of magnesium per ton, as against the pots treated with larger quantities of magnesite

(100 and 101), which show 5.52 pounds of calcium and 10.88 pounds of magnesium.

Gile and Ageton (5, p. 44) show that many plants such as soybeans, sugar cane, and sunflower have higher lime contents when grown upon calcareous soils and that the increase in lime content tends to decrease the amount of magnesia, iron, and potash.

TABLE VII.—*Analysis of wheat and alfalfa grown in magnesite—series E and F*

Pot No.	Substance added. Calcium.	Substance added. Magnesium.	Composition of plants. Calcium.		Composition of plants. Magnesium.		Molecular ratio of calcium to magnesium.
	Per cent.	*Per cent.*	*Mgm.*	*Per cent*	*Mgm.*	*Per cent.*	
WHEAT STRAW							
89	0.014	0.016	12.0	0.165	9.36	0.130	5: 6.5
90 and 91	.222	.100	10.55	.154	16.55	.241	5:13
100 and 101	1.332	.60	24.4	.276	48.1	.544	5:16.4
102 and 103	.967	.60	24.1	.237	32.3	.317	5:11.1
ALFALFA HAY							
105	.014	.016	87.4	1.275	41.0	.598	5:9.3
106 and 107	.222	.100	106.8	1.49	45.1	.63	5:3.8
116 and 117	1.332	.60	98.5	1.345	56.0	.69	5:4.2
118 and 119	.967	.60	93.2	1.55	39.2	.653	5:3.5
ALFALFA ROOTS							
105	.014	.016	25.4	.672	14.52	.385	5:4.8
106 and 107	.222	.10	55.7	.89	43.8	.64	5:6
116 and 117	1.332	.60	63.0	1.48	61.1	1.434	5:8
118 and 119	.967	.60	65.2	1.73	35.8	.95	5:4.6

EFFECT OF MAGNESIUM AND CALCIUM IN CALCAREOUS SOIL, MAGNESITE, DOLOMITE, AND PREPARED CARBONATES UPON WHEAT AND ALFALFA (SERIES G AND H)

It can be seen from Table VIII that the ratios of calcium to magnesium vary from one of 5 to 3.8 to one of 5 to 125 and that in both cases considerable growth occurred. However, in pots 135, 136, 161, and 162, receiving 35 per cent of magnesite and 100 gm. of calcium carbonate, the plants showed a yellow color and some sickness; still, in the case of alfalfa the plants were able to set some seed. The yields in pots 123, 124, 149, and 150, which received calcareous soil only, were somewhat less than where sand was mixed with the soil, owing to the soil being decidedly plastic and possessing a less desirable physical condition.

Plate LXXXIV shows the difference between some of the treatments in series G. Observe the small growth of the wheat in the pot receiving 6 per cent of magnesium in magnesite. This is due to the physical condition caused by applying the magnesite in a finely ground form, which caused a setting that resembled cement, whereas in the pot with 10 per cent of magnesium almost twice as much magnesite was applied, but in a coarser form. For the ratios in these pots see Table VIII.

Plate LXXXIV shows alfalfa growing under similar treatments.

TABLE VIII.—*Yields of wheat and alfalfa (in grams per pot on water-free basis) in soil, dolomite, and magnesite—series G and H*

Treatment.	Molecular ratio of calcium to magnesium.	Wheat, series G.			Alfalfa, series H.			
		Pot No.	Tops.	Roots.	First crop.	Second crop.	Third crop.	Pot No.
None	....	121	15.4	6.53	3.6	9.59	5.63	147
	....	122	1.08	....	2.28	....	....	148
Percentage of magnesium in calcareous soil:								
2.64	5:3.8	123	21.93	7.15	7.22	7.47	12.6	149
	5:3.8	124	21.0	14.7	7.04	7.22	10.02	150
1.328	5:3.8	125	26.9	16.2	9.41	11.7	13.0	151
	5:3.8	126	27.3	10.4	9.59	12.35	10.9	152
0.672	5:3.8	127	24.5	19.4	10.11	13.72	12.3	153
	5:3.8	128	28.62	9.25	10.02	12.3	9.59	154
0.344	5:3.9	129	31.7	14.4	10.28	9.68	10.71	155
	5:3.9	130	32.6	10.32	9.68	10.46	7.83	156
Percentage of magnesium in magnesite plus calcium carbonate:								
2.0	5:4	131	35.5	11.05	9.15	8.97	8.8	157
	5:4	132	35.8	10.05	10.9	9.86	8.88	158
6.0	5:75	133	9.7	4.26	5.28	8.45	5.2	159
	5:75	134	30.8	1.18	5.9	10.62	3.69	160
10.0	5:125	135	18.2	6.25	4.48	5.02	2.28	161
	5:125	136	17.4	6.16	10.11	9.77	9.59	162
Percentage of magnesium in dolomite C1:								
12.7	5:5.2	137	2.17	....	5.2	9.77	9.77	163
	5:5.2	138	3.26	....	....	....	....	164

One of the most noticeable facts brought out in these series is the great sensitiveness of the plants to small quantities of calcium and magnesium, also their ability to utilize relatively insoluble forms of these two materials. In pots 121 and 122, Table IX, and pots 147 and 148, Table X, the plants were grown in extracted sand receiving no calcium and magnesium and were able to obtain considerable quantities that had not been removed by the acid extractions. The alfalfa was even able to mature a few seeds.

TABLE IX.—*Analysis of wheat grown in soil, dolomite, and magnesite—series G*

Pot No.	Substance added.		Composition of plants.				
	Calcium.	Magnesium.	Calcium.		Magnesium.		Molecular ratio of calcium to magnesium.
			Mgm.	*Per cent.*	*Mgm.*	*Per cent.*	
WHEAT STRAW							
121	0.014	0.016	24.65	0.165	20.4	0.132	5: 7
123 and 124	5.78	2.64	76.1	.358	52.9	.249	5: 5.7
125 and 126	2.897	1.328	130.0	.48	78.7	.29	5: 5
129 and 130	.732	.344	156.1	.485	97.5	.305	5: 5.2
131 and 132	4.44	2.0	88.6	.248	188.0	.527	5:17.7
135 and 136	.666	10.0	66.8	.375	170.0	.955	5:21.2
137 and 138	20.47	12.7	15.6	.574	19.9	.73	5:12.7
WHEAT ROOTS							
121	.014	.016	18.7	.287	8.14	.125	5:3.6
123 and 124	5.78	2.64	85.7	.795	35.6	.33	5:3.4
125 and 126	2.897	1.328	76.5	.584	44.3	.332	5:4.8
129 and 130	.732	.344	63.5	.513	30.7	.248	5:4
131 and 132	4.44	2.0	129.4	1.224	163.9	1.6	5:10.8
135 and 136	.666	10.0	22.25	.358	44.75	.72	5:16.8

The high percentage of magnesium in the plants grown in pots receiving 35 per cent of magnesite is also characteristic of tolerance. Likewise a high magnesium content tends to accompany plant sickness. In the case of wheat grown in dolomite, pots 137 and 138, there was a higher percentage of calcium than in any other treatment. A ton of water-free material contained 11.48 pounds of calcium and 14.6 pounds of magnesium, but a ton of dry matter from the treatment with 25 per cent of magnesite showed 7.5 pounds of calcium and 19.1 pounds of magnesium per ton, as against the check in sand which contained 3.3 pounds of calcium and 2.64 pounds of magnesium. Alfalfa tends to show the same thing, except that it is a decidedly heavier feeder upon these two elements than is the wheat crop.

The wheat, Table VIII, was planted on January 26, 1914, and harvested on May 27, 1914, making 121 days of growth. The alfalfa was also planted on the above date and the first crop harvested on May 27, 1914. The second crop was harvested 127 days later, on October 1, 1914, and the third crop on November 12, 1914, after 42 days of additional growth.

By comparing pot 147, Table X, for the three crops, it will be seen that the second crop of alfalfa contained practically three times as much calcium and magnesium per ton as did the first crop, while the time of growth was about the same. The third crop contained about twice as much calcium and magnesium per ton as did the first crop, and its period

of growth was only 42 days. This is due chiefly to the extensive development of roots, making it possible to utilize more of the small quantities of calcium and magnesium remaining in the extracted sand, for in the other pots where these two elements were added such striking differences do not occur in the different crops.

To each pot receiving 15 alfalfa seeds, 0.19 mgm. of calcium and 0.32 mgm. of magnesium were added in the seed, and for the three crops 164.5 mgm. of calcium and 90.72 mgm. of magnesium were removed. This indicates to what extent the plants may attack relatively insoluble compounds.

TABLE X.—*Analysis of alfalfa grown in soil, dolomite, and magnesite—series H*

Pot No.	Substance added.		Composition of plants.				
	Calcium.	Magnesium.	Calcium.		Magnesium.		Molecular ratio of calcium to magnesium.
			Mgm.	*Per cent.*	*Mgm.*	*Per cent.*	
ALFALFA, FIRST CROP							
147 and 148	0.014	0.016	11.2	0.382	5.72	0.198	5:4.3
149 and 150	5.78	2.64	98.41	1.382	26.52	.373	5:2.2
151 and 152	2.897	1.328	136.0	1.432	33.92	.357	5:2
155 and 156	.732	.344	127.8	1.28	34.5	.346	5:2.2
157 and 158	4.44	2.0	92.5	.922	74.5	.744	5:6.8
159 and 160	.666	6.0	23.8	.426	52.3	.936	5:18.3
161 and 162	.666	10.0	76.7	1.05	83.7	1.148	5:9.1
163	20.47	12.7	34.2	.66	33.8	.633	5:8
ALFALFA, SECOND CROP							
147	.014	.016	105.3	1.096	63.8	.665	5:5
149 and 150	5.78	2.64	117.5	1.615	31.8	.434	5:2.2
151 and 152	2.897	1.328	172.0	1.402	50.0	.407	5:2.5
155 and 156	.732	.344	114.5	1.138	50.0	.517	5:3.7
157 and 158	4.44	2.0	103.4	1.098	67.6	.718	5:5.4
159 and 160	.666	6.0	75.0	.785	76.5	.803	5:8.5
161 and 162	.666	10.0	102.0	1.381	73.6	1.00	5:6
163	20.47	12.7	104.4	1.068	69.4	.711	5:5.5
ALFALFA, THIRD CROP							
147	.014	.016	48.0	.854	21.22	.378	5:3.6
149 and 150	5.78	2.64	110.0	.974	31.6	.291	5:2.4
151 and 152	2.897	1.328	110.2	.922	32.2	.27	5:1.0
155 and 152	.732	.344	78.75	.955	29.62	.32	5:2.8
157 and 158	4.44	2.0	85.0	.962	40.7	.461	5:4
159 and 160	.666	6.0	40.8	.922	39.8	.783	5:7
161 and 162	.666	10.0	51.6	.87	54.7	.922	5:9.2
163	20.47	12.7	96.5	.99	49.0	.503	5:4.2

EFFECT OF MAGNESITE AND DOLOMITE UPON WHEAT AND SOYBEANS (SERIES I AND J)

Series I had wheat grown in the pots and then turned under, and wheat was then replanted in the same pots; while series J had cowpeas grown and turned under and then soybeans planted, except in pots 182 and 183, from which the cowpeas were removed before the soybeans were planted. The cowpea hay grown in pots 182 and 183 contained 0.4 per cent of calcium and 0.179 per cent of magnesium, in a ratio of 5 to 5.7, and removed from each pot 32 mgm. of calcium and 14.32 mgm. of magnesium. In 10 seeds planted there was 0.58 mgm. of calcium and 1.59 mgm. of magnesium. The above pots contained extracted sand.

Figure 1 of Plate LXXXV shows the effect of succeeding crops when grown upon extracted sand. The pot at the left marked "sand only" has had no other crop preceding it, while in the middle pot cowpeas were grown and removed, taking out some of the most readily available calcium and magnesium. From the pot at the right three crops of alfalfa were removed, taking out 164.5 mgm. of calcium and 90.72 mgm. of magnesium.

Dolomite has no detrimental effect upon the crops used throughout these experiments. However, the addition of larger quantities of magnesite—for example, 35 per cent—caused considerable yellowing of the leaves, and the plants were able to mature but few seeds. Plate LXXXV, figure 2, shows that the plants growing in dolomite have quite a number of bean pods, while in the magnesite pot none are visible and the uppermost leaves are sickly. This yellowing of the uppermost leaves while the lower ones remain green differs from true translocation and accompanies high magnesium applications. The yellow leaves have a higher magnesium content than do the healthy ones, as sickly leaves from the plants taken from pot 185 show 0.955 per cent of calcium and 1.11 per cent of magnesium, while the healthy leaves from the same plants showed 0.896 per cent of calcium and 0.88 per cent of magnesium, respectively.

Schulze and Godet (31) found more calcium in the husk and more magnesium in the seed of lupine, pine, pumpkin, castor bean, sunflower, and various nuts.

Plate LXXXVI, figure 1, shows the comparative growths of soybeans in brown silt loam and dolomite. Evidently the brown silt loam would have been improved by applications of some limestone or dolomite.

The differences of yields of duplicates in Table XI are due chiefly to the differences in the duration of growth. In the wheat, series I, pots 173, 175, 177, and 179 were harvested 65 days after planting, while their duplicates were harvested 12 days earlier. In the soybean, series J, pots 181, 184, 186, and 188 were harvested 53 days after planting, while their duplicates were permitted to mature, standing until 80 days after planting.

TABLE XI.—*Yields of wheat and soybeans (in grams per pot on the water-free basis) in dolomite, magnesite, and sand—series I and J*

Treatment.	Molecular ratio of calcium to magnesium.	Wheat, series I.			Soybeans, series J.		
		Pot No.	Tops.	Roots.	Pot No.	Tops.	Roots.
None	......	173	0.9	0.4	181	1.0	0.5
	......	174	.3	.4	182	1.2	......
Percentage of magnesium in magnesite plus calcium carbonate:							
2	5:4	175	4.8	2.9	183	5.6	......
	5:4	176	1.6	1.1	184	4.7	.9
10	5:125	177	5.3	1.7	185	4.0	......
	5:125	178	1.8	1.0	186	3.2	.8
Percentage of magnesium in dolomite C3:							
12	5:5.2	179	5.3	3.2	187	6.5	......
	5:5.2	180	1.9	.9	188	3.4	.7

Table XII shows the analyses of wheat grown in series I.

TABLE XII.—*Analysis of straw of wheat grown in dolomite, magnesite, and sand—series I*

Pot No.	Substance added.		Composition of plants.				
	Calcium.	Magnesium.	Calcium.		Magnesium.		Molecular ratio of calcium to magnesium.
	Per cent.	*Per cent.*	*Mgm.*	*Per cent.*	*Mgm.*	*Per cent.*	
174	0.014	0.016	1.32	0.44	0.58	0.127	5:2.4
173	.014	.016	1.21	.135	1.26	.14	5:7.1
176	4.44	2.0	10.88	.68	13.04	.815	5:9.9
175	4.41	2.0	21.36	.445	36.78	.783	5:14.6
178	.666	10.0	8.87	.493	18.03	1.002	5:16.9
177	.666	10.0	16.16	.305	40.54	.765	5:22
180	20.47	12.7	10.26	.54	11.38	.599	5:7.2
179	20.47	12.7	24.11	.455	22.15	.418	5:7.6

Comparisons of the contents of plants at different stages of growth are reported in Table XIX.

THE EFFECT OF MAXIMUM QUANTITY OF CALCIUM AND MAGNESIUM UPON WHEAT AND SOYBEANS IN SAND (SERIES K)

Analysis of sand treated by different methods shows the hot-extracted sand to contain only slightly less calcium but considerably less magnesium than the cold-extracted sand.

Table XIX shows the analysis of wheat and soybeans grown in such sands. It can be seen that the soybeans contained only slightly more of these two elements than was in the seed, but it must be remembered that scarcely any growth occurred. However, the wheat, pots 193 to 196, contained from 12 to 22 times as much calcium and 4 times as much

magnesium as was added in the seed. Now, in pots 199 to 202, where a small amount of easily available calcium had been applied, the percentage in the plants was materially increased.

Attempts were made to grow wheat and cowpeas in paraffin, so that they would have no access to calcium and magnesium. However, this permitted but little growth, and analyses of the total plants thus grown showed their calcium and magnesium contents to be equivalent to the amount present in the seed.

TABLE XIII.—*Analysis of wheat and soybeans grown in extracted sand—series K*

SOYBEAN PLANT

Pot No.	Treatment of sand.	Composition of plants.					Substance added in seed.	
		Calcium.		Magnesium.		Molecular ratio of calcium to magnesium.	Calcium.	Magnesium.
		Mgm.	*Per ct.*	*Mgm.*	*Per ct.*		*Mgm.*	*Mgm.*
189 and 190[a]	Extracted with hydrochloric acid in the cold.	2.15	0.293	2.77	0.376	5:10.6	1.16	2.32
191 and 192	Extracted with hydrochloric acid on steam bath.	1.5	.335	1.65	.369	5: 9.2	1.16	2.32

WHEAT PLANT

Pot No.	Treatment of sand.	Calcium, Mgm.	Calcium, Per ct.	Magnesium, Mgm.	Magnesium, Per ct.	Molecular ratio of calcium to magnesium.	Substance added in seed: Calcium, Mgm.	Substance added in seed: Magnesium, Mgm.
193 and 194	Extracted with hydrochloric acid in the cold.	.67	.22	.78	.256	5: 9.7	.03	.18
195 and 196	Extracted with hydrochloric acid on steam bath.	.36	.168	.72	.337	5:16.7	.03	.18
197 and 198	0.2 gm. sodium bicarbonate ($NaHCO_3$).	.80	.155	.74	.144	5: 8	.03	.18
199 and 200	0.2 gm. sodium bicarbonate ($NaHCO_3$) 0.05 gm. calcium nitrate ($Ca(NO_3)_2$).	1.14	.3	.35	.093	5: 2.5	.03	.18
201 and 202	0.2 gm. sodium bicarbonate ($NaHCO_3$) 0.05 gm. calcium nitrate ($Ca(NO_3)_2$) 0.0317 gm. magnesium sulphate ($MgSO_4$)	.34	.247	.48	.35	5:11.8	.03	.18

[a] The containers in this series were tall Jena beakers holding 1,350 gm. of sand.

From Table XIII it can be seen that the plants contained more calcium and magnesium than was added in the seed, thus showing their power to obtain these two elements from sand that had been previously extracted with acid.

EFFECT OF MAGNESIUM AND CALCIUM IN SULPHATES, CHLORIDS, AND CARBONATES UPON WHEAT AND SOYBEANS IN SAND (SERIES L AND M)

When calcium and magnesium were applied in sulphates, chlorids, and carbonates the smaller applications gave the highest yields. As recorded in Table XIV, 0.1 per cent of magnesium in the carbonate inhibited germination and permitted no growth, whereas this quantity in the sulphates and chlorids gave considerable growth; however, the chlorids were more detrimental than the sulphates, while at lower concentrations, such as 0.01 and 0.001 per cent of magnesium, the carbonates gave the best growth, the chlorids being the most detrimental. In the case of soybeans all the chlorid treatments permitted practically no seed formation, while treatment with smaller quantities of carbonates gave considerable seed. The root formation was relatively the same as the top growth, the detrimental effect accompanied short thick roots which appeared brownish or reddish brown. Plate LXXXVII shows this comparative root growth. Plate LXXXVIII, figure 1, shows the comparisons of wheat when grown in extracted sand and in dolomite. Figure 2 shows the retarded growth of wheat due to the chlorids of magnesium.

TABLE XIV.—*Yields of wheat and soybeans (in grams per pot on the water-free basis) in the sulphates, chlorids, and carbonates of magnesium and calcium—series L and M*

Treatment.	Molecular ratio of calcium to magnesium.	Wheat, series L.			Soybeans, series M.		
		Pot No.	Tops.	Roots.	Pot No.	Tops.	Roots.
None	......	219	5.8	3.0	237	1.3	0.3
None	......	220	2.1	1.0	238	2.0	......
Percentage of magnesium in magnesium sulphate plus calcium sulphate:							
0.1	5:4	203	2.4	1.4	221	3.2	......
	5:4	204	3.3	1.1	222	2.6	.6
.01	5:4	205	3.8	1.5	223	5.5	......
	5:4	206	4.4	1.3	224	4.9	1.0
.001	5:4	207	5.1	1.7	225	3.6	.7
	5:4	208	3.8	1.6	226	4.0	......
Percentage of magnesium in magnesium chlorid plus calcium chlorid:							
0.1	5:4	209	1.6	.7	227	2.4	......
	5:4	210	1.5	.6	228	2.1	.5
.01	5:4	211	3.1	1.3	229	2.6	.8
	5:4	212	3.5	1.6	230	2.7	.6
.001	5:4	213	5.2	2.5	231	3.6	1.0
	5:4	214	8.8	4.7	232	3.5	......
Percentage of magnesium in magnesium carbonate plus calcium carbonate:							
0.01	5:4	215	6.8	4.0	233	2.0	.7
	5:4	216	3.3	1.5	234	7.8	......
.001	5:4	217	6.8	7.8	235	6.3	1.2
	5.4	218	4.2	2.6	236	7.6	......

In Table XIV pots 205, 208, 210, 212, 213, 216, 218, and 220 were harvested 53 days after planting. Their duplicates were permitted to grow 12 days longer. Pots 221, 223, 226, 227, 229, 232, 235, and 237 were harvested at maturity, 80 days from the time of planting. Duplicates were grown only 53 days. The analyses are given in Tables XV and XVI.

TABLE XV.—*Analysis of straw of wheat grown with sulphates, chlorids, and carbonates of calcium and magnesium—series L*

Pot No.	Substance added: Calcium.	Substance added: Magnesium.	Composition of plants: Calcium, Mgm.	Composition of plants: Calcium, Per cent.	Composition of plants: Magnesium, Mgm.	Composition of plants: Magnesium, Per cent.	Molecular ratio of calcium to magnesium.
SULPHATES							
203	0.222	0.1	18.48	0.77	15.45	0.644	5: 6.9
205	.022	.01	26.6	.70	38.86	.97	5:11.5
208	.002	.001	15.2	.40	5.73	.151	5: 3.1
CHLORIDS							
210	.222	.1	22.5	1.5	11.77	.785	5: 4.3
212	.022	.01	12.67	.362	9.66	.276	5: 6.8
213	.002	.001	22.36	.43	9.05	.174	5: 3.3
CARBONATES							
216	.022	.01	9.24	.28	20.33	.616	5 18.3
218	.002	.001	17.28	.432	15.68	.392	5: 7.5
220	....	....	5.31	.253	2.58	.123	5: 4

The plants used in the experiments in Table XV were harvested when 53 days old.

TABLE XVI.—*Analysis of soybean hay grown with sulphates, chlorids, and carbonates of calcium and magnesium—series M*

Pot No.	Substance added: Calcium.	Substance added: Magnesium.	Composition of plants: Calcium, Mgm.	Composition of plants: Calcium, Per cent.	Composition of plants: Magnesium, Mgm.	Composition of plants: Magnesium, Per cent.	Molecular ratio of calcium to magnesium.
SULPHATES							
222	0.222	0.1	30.94	1.19	31.46	1.21	5:8.4
224	.022	.01	41.89	.885	31.45	.642	5:6.2
225	.002	.001	21.24	.59	12.24	.34	5:4.8
CHLORIDS							
228	.222	.1	15.39	.733	13.96	.665	5:7.5
230	.022	.01	25.11	.93	19.54	.724	5:6.4
231	.002	.001	13.89	.386	10.26	.285	5:6.1
CARBONATES							
233	.022	.01	27.26	.94	23.02	.825	5:7.3
235	.002	.001	72.13	1.145	38.36	.600	5:4.4
237	....	....	7.15	.55	4.04	.311	5:4.7

EFFECT OF MAGNESIUM AND CALCIUM IN CALCAREOUS SOIL, DOLOMITE, AND MAGNESITE, AFTER ALFALFA, UPON SOYBEANS (SERIES N)

The soybeans in series N were grown after three crops of alfalfa had been removed and the roots turned under. Pots 239 and 240 showed but a small amount of growth. Pots 251, 252, and 253 showed considerable organic growth, but the plants were sickly and did not yield much seed. The yields are reported in Table XVII. Analyses of the plants, Table XVIII, show treatments with the largest quantities of magnesium in magnesite, giving the plants with the greatest magnesium content and containing as much as 29.92 pounds of magnesium per ton. Also proportionately the highest amount of calcium and magnesium were found in these pots. The check pots, 239 and 240, showed the lowest percentage of calcium and magnesium in the plants grown.

TABLE XVII.—*Yields of soybeans (in grams per pot on the water-free basis) grown after alfalfa in soil, magnesite, and sand—series N*

Treatment.	Molecular ratio of calcium to magnesium.	Soybeans, series N.			
		Pot No.	Tops.	Roots.	Seeds.
None	....	239	1.3	....	....
	....	240	1.6	....	....
Percentage of magnesium in calcareous soil:					
2.64	5:3.8	241	5.6	0.6	....
	5:3.8	242	7.3	....	2.[illegible]
1.328	5:3.8	243	7.2	1.2	....
	5:3.8	244	6.2	....	2.2
.672	5:3.8	245	8.5	....	4.[illegible]
	5:3.8	246	6.1	1.2	....
.344	5:3.9	247	12.1	....	6.[illegible]
	5:3.9	248	6.5	1.0	....
Percentage of magnesium in magnesite plus calcium carbonate:					
0.2	5:4	249	6.6	....	1.[illegible]
	5:4	250	6.6	2.0	....
10	5:125	252	3.8	.7	....
	5:125	253	8.5	....	....
Percentage of magnesium in magnesite:					
0.6	5:75	251	4.0	.7	....
Percentage of magnesium in dolomite C_3:					
12.7	5:5.2	254	3.8	.7	....

Pots 240, 242, 244, 245, 247, 249, and 253 were harvested at maturity, or 80 days after planting.

The plants used in the experiments in Table XVIII were 53 days old.

Table XIX shows the differences in composition of wheat grown under the same treatment but harvested at different periods of growth. The first plants were harvested 53 days after being planted. It was the original plan to allow the duplicates to mature, but owing to attacks of mildew they were harvested 12 days later.

TABLE XVIII.—*Analysis of soybeans grown after alfalfa in soil, magnesite, and sand—series N*

Pot No.	Substance added.		Composition of plants.				Molecular ratio of calcium to magnesium.
	Calcium.	Magnesium	Calcium.		Magnesium		
	Per cent.	*Per cent.*	*Mgm.*	*Per cent.*	*Mgm.*	*Per cent.*	
239	0.014	0.016	7.02	0.54	4.6	0.354	5: 5.4
241	5.78	2.64	109.76	1.96	41.5	.741	5: 3.1
243	2.897	1.328	131.0	1.82	52.7	.732	5: 3.3
246	1.455	.672	90.28	1.48	47.88	.785	5: 4.4
248	.732	.344	76.62	1.225	48.42	.745	5: 5.1
250	4.44	2.0	82.83	1.225	76.54	1.19	5: 7.9
251	.666	6.0	29.04	.726	30.40	.985	5:11.3
252	.666	10.0	32.83	.864	56.85	1.496	5:14.4
254	20.47	12.7	46.96	1.236	31.73	.835	5: 5.6

The percentages of calcium and magnesium were greater in the plants harvested in the earlier stages of growth. In the wheat the proportion of magnesium to calcium was somewhat greater in the later stages of growth. Still it must be remembered that the plants were by no means thoroughly matured. This was not the case with the soybeans, as is shown by Table XX. Soybean plants at maturity, or 80 days after planting, showed higher percentages of calcium and magnesium than at the end of 53 days of growth, except the checks in sand and those having had extremely small applications.

TABLE XIX.—*Composition of wheat at different stages of growth*

Treatment.	Wheat 53 days old.				Wheat 65 days old.		
	Pot No.	Calcium.	Magnesium.	Molecular ratio of calcium to magnesium.	Calcium.	Magnesium.	Molecular ratio of calcium to magnesium.
None	173	0.44	0.127	5: 2.4	0.135	0.14	5: 7.1
Percentage of magnesium in dolomite C_3:							
12.7	179	.54	.599	5: 9.2	.455	.418	5: 7.6
Percentage of magnesium in magnesite:							
10	177	.493	1.002	5:16.9	.305	.765	5:21
2	175	.68	.815	5: 9.9	.445	.783	5:14.6
Percentage of magnesium in magnesium sulphate:							
0.1	203	.77	.644	5: 6.9	.61	.54	5: 7.3
0.01	205	.70	.97	5:11.5	.40	.646	5:13.4
0.001	207	.40	.151	5: 3.1	.255	.158	5: 5.1
Percentage of magnesium in magnesium chlorid:							
0.1	209	1.5	.785	5: 4.3	.984	.604	5: 5
0.01	211	.362	.276	5: 6.8	.30	.31	5: 8.6
0.001	213	.43	.174	5: 3.3	.245	.163	5: 5.5
Percentage of magnesium in magnesium carbonate:							
0.01	215	.28	.616	5:18.3	.405	.587	5:12
0.001	217	.432	.392	5: 7.5	.455	.316	5: 5.8
None	219	.253	.123	5: 4	.15	.16	5: 8.8

Seissl (32) experimented with a large number of plants in various stages of growth and found a slight fluctuation in the ratio of calcium to magnesium in the ash analyzed in the different years. In nearly every instance there was a progressive increase in the ratio of the lime to the magnesia content towards autumn. In only two cases was the lime content greater than that of the magnesia.

TABLE XX.—*Composition of soybeans at different periods of growth*

Treatment.	Pot No.	Soybeans 53 days old.			Soybeans 80 days old.		
		Calcium.	Magnesium.	Molecular ratio of calcium to magnesium.	Calcium.	Magnesium.	Molecular ratio of calcium to magnesium.
		Per cent.	*Per cent.*		*Per cent.*	*Per cent.*	
None	181	0.344	0.449	5:10.8	0.29	0.28	5:8
Percentage of magnesium in dolomite C3:							
12.7	187	1.546	.964	5:5.2	2.07	1.3	5:5.2
Percentage of magnesium in magnesite:							
10	185	.96	1.032	5:9	.75	1.138	5:12.6
2	183	1.357	.838	5:5.2	1.15	.815	5:5.9
Percentage of magnesium in magnesium sulphate:							
0.1	221	1.19	1.21	5:8.4	1.71	2.28	5:11.1
.01	223	.855	.642	5:6.2	1.215	1.31	5:9
.001	225	.59	.34	5:4.8	.6	.356	5:4.8
Percentage of magnesium in magnesium chlorid:							
0.1	227	.733	.665	5:7.5	2.55	1.33	5:4.3
.01	229	.93	.724	5:6.4	.65	.495	5:6.3
.001	231	.386	.285	5:6.1	.27	.255	5:7.9
Percentage of magnesium in magnesium carbonate:							
0.01	233	.94	.825	5:7.3	1.13	1.19	5:8.7
.001	235	1.145	.609	5:4.4	1.57	.399	5:2.1
None	237	.55	.311	5:4.7	.36	.184	5:4.2
Percentage of magnesium in calcareous soil:							
2.64	241	1.96	.741	5:3.1	3.0	.997	5:2.[illegible]
1.32	243	1.82	.737	5:3.3	3.65	1.26	5:2.[illegible]
.672	245	1.48	.785	5:4.4	2.7	1.016	5:3.[illegible]
.344	247	1.225	.745	5:5.1	2.11	.79	5:3.1
None	239	.54	.354	5:5.4	.17	.118	5:9.2
Percentage of magnesium in magnesite:							
2	249	1.255	1.20	5:7.9	1.55	1.55	5:8.[illegible]
10	252	.864	1.496	5:14.4	1.145	2.166	5:15.7[illegible]

TABLE XXI.—*Tolerance of crops for calcium and magnesium*

Treatment.	Molecular ratio of calcium to magnisium.	Wheat.			Alfalfa.		
		Calcium.	Magnesium.	Molecular ratio of calcium to magnesium.	Calcium	Magnesium.	Molecular ratio of calcium to magnesium.
None	5:9.5	0.187	0.108	5:5.1	0.317	0.164	5:3.9
Percentage of magnesium in dolomite C1:							
0.2	5:4.8	.293	.271	5:7.6	2.565	.431	5:1.4
0.6	5:4.8	.386	.421	5:9.1	2.022	.649	5:2
Percentage of magnesium in brown-gray silt loam:							
0.352	5:9.6	.296	.256	5:7.2	1.595	.398	5:2.2
Percentage of magnesium in dolomite C3:							
12.7	5:5.2	.574	.730	5:12.6	1.063	.711	5:5.5
Percentage of magnesium in magnesite:							
10	5:125	.375	.955	5:21	1.381	1.00	5:6

The yields in the pots in Table XXI were practically the same on the different treatments. This shows the alfalfa to contain more calcium and magnesium than the wheat. Some of the other treatments show higher percentages of calcium and magnesium, but the yields are not comparable. It might be interesting to note that soybean hay at maturity contained per ton as much as 73 pounds of calcium and 25.2 pounds of magnesium when grown in a mixture of equal parts of sand and calcareous soil, but when grown in a mixture containing 40 per cent of magnesite there were 22.9 pounds of calcium and 43.3 pounds of magnesium per ton.

DISCUSSION

The experiments reported here extend over a period of three years (1912 to 1915) and include approximately 300 pot cultures and upwards of 300 duplicate determinations of calcium and magnesium.

Difficulty was experienced in finding a medium that was free from calcium and magnesium, and which would still approach soil conditions. Attempts were made to grow plants in aluminum turnings but without success, probably due to the formation of some aluminum salts when the plant foods were added. It is well known that aluminum salts disturb the physiological functioning of plant organs.

Wheat and cowpeas grown in granular paraffin without the addition of calcium and magnesium showed in the total plant only an amount equal to that furnished by the seed.

The difference in the medium in which the plants were grown caused different effects upon the plants. Brown silt loam was a better medium than sand when treated with chemically pure magnesium carbonate, even though it already contained 25 times as much calcium and magnesium as did the sand. Still sand would have an ameliorating effect when compared with solution cultures. Jensen (10) found that in quartz sand a much higher concentration of salts was required to cause death than in water cultures.

As previously shown under literature studies it is quite generally believed that plants have to some extent a selective absorption. The results here seem to indicate such a condition, for the dolomites used tend to go into solution in a molecular ratio, but the plants failed to take them up in this ratio. The tendency of the plants under these conditions was to take up relatively larger molecular proportions of magnesium than of calcium. Analysis of the plants show that they do not necessarily take up calcium and magnesium in the same ratio as applied, as, for example, in dolomite C3 the ratio of calcium to magnesium is 5:5.2, while the plants may and do take it up in a ratio of 5:7 or 5:3.95.

In the case of the addition of 25 per cent of magnesite the ratio of calcium to magnesium was 5:125, while in some of the plants grown in such treatment the ratio varied from 5:15 to 5:21. Wheat grown in soil treated with 6 per cent of dolomite showed in the tops a ratio of 5:9.1 and in the roots a ratio of 5:4.35, or for the whole plant a ratio of 5:6.3, while in dolomite C1 it was 5:4.8. Alfalfa grown in the same treatment showed for the entire plant a ratio of 5:4.2, but when grown in soil treated with dolomite C3 the ratio for the total alfalfa plant was 5:3.95, while in the dolomite the ratio of the calcium to the magnesium was 5:5.2.

The chlorids of calcium and magnesium were more detrimental to wheat and soybeans than were the sulphates at concentrations up to 0.1 per cent of magnesium. This amount of magnesium in the prepared carbonate entirely inhibited growth, whereas lower concentration gave better growth than either the sulphates or chlorids.

Wheat 65 days old showed smaller percentages of calcium and magnesium than did similarly treated wheat at 53 days of growth, but the total amount of these two elements in the plants increased with the duration of growth.

Soybeans at maturity, or 80 days after planting, showed for the hay higher calcium and magnesium contents than at 53 days of growth, except in the case of the checks and those treated with extremely small quantities. Some of the samples showed as much as 73 pounds of calcium and 25.2 pounds of magnesium per ton when grown in a mixture of one-half sand and one-half calcareous soil, but when grown in soil containing 35 per cent of magnesite there were 22.9 pounds of calcium

and 42.3 pounds of magnesium per ton; whereas the checks contained 5.8 pounds of calcium and 5.6 pounds of magnesium.

Whenever excessive amounts of magnesium were applied, there was a characteristic appearance of yellow leaves. The uppermost leaves became yellow and gradually died, while the lower leaves remained green. This condition is characteristic of magnesium sickness and just the reverse of the effects produced by translocation processes.

The general tendency is for the percentages of calcium and magnesium in the plants to increase with the increase in size of application. Likewise a high magnesium content in the plant tends to accompany plant sickness, as sickly and healthy leaves from the same soybean plant showed, respectively, 1.11 per cent of magnesium as against 0.88 per cent magnesium.

All varieties of the seed used contained more magnesium than calcium, while ordinarily the remainder of the plant contained more calcium than magnesium. This conforms with the data of Schulze and Godet, who report more calcium in the husk and more magnesium in the seed.

Nitrogen was applied to the legumes as well as to the cereals, so as to be sure that this was not the limiting factor.

In a number of instances the differences in the yields between duplicates were as great as between the different treatments. At several periods during the growth of the plants parasites caused injuries, sometimes great enough to necessitate harvesting the crop.

CONCLUSIONS

(1) Wheat, soybeans, alfalfa, and cowpeas grew normally either in 96 per cent of dolomite and 4 per cent sand, 100 per cent of magnesian limestone, or in sand containing 7 per cent of magnesite.

(2) Dolomite up to 40 per cent proved beneficial to plant growth. These results indicate that dolomite and magnesian limestone will not be detrimental as applied in agricultural practices.

(3) Applications of prepared magnesium carbonate up to 0.7 per cent caused no injury in brown silt loam, but 0.35 per cent prevented the growth of all plants tested in sand.

(4) The crop yields and the ratio of calcium to magnesium in the plants bear no direct relation to the ratio in the natural carbonates applied.

(5) Different ratios of calcium to magnesium within rather wide limits produced no marked differences in yields.

(6) Increasing the size of applications increased the calcium and magnesium content of plants.

(7) A tolerance of calcium and magnesium occurred in all varieties of plants grown. With approximately identical yields, wheat straw

grown in sand, brown silt loam, dolomite, and soil containing 35 per cent of magnesite showed calcium contents varying between 0.165 per cent and 0.547 per cent and magnesium contents varying between 0.132 per cent and 0.955 per cent.

(8) Acid extractions failed to remove all the calcium and magnesium from the sand. There remained after the various extractions from 763 to 852 mgm. of calcium and from 540 to 960 mgm. of magnesium per 6,000 gm. of sand.

(9) The plants possessed a decided ability to obtain calcium and magnesium from sand extracted with strong hydrochloric acid, as borne out by the following example: Three crops of alfalfa removed from acid-extracted sand 164.43 mgm. more calcium and 90.4 mgm. more magnesium than was contained in seeds similar to those planted.

LITERATURE CITED

(1) DASSONVILLE, Ch.
1898. Influence des sels minéraux sur la forme et la structure des végétaux. *In* Rev. Gén. Bot., t. 10. no. 109, p. 15–25, fig. 13–14; no. 110, p. 59–68; no. 111, p. 102–124, fig. 23; no. 112, p. 161–170; no. 113, p. 193–199; no. 114, p. 238–260, fig. 27; no. 115, p. 289–304; no. 116, p. 335–341; no. 117, p. 370–380, pl. 5–14.

(2) DOJARENKO, A.
1903. Remarks on Loew's hypothesis concerning the rôle of lime in soils. (Abstract.) *In* Exp. Sta. Rec., v. 15, no. 2, p. 127. 1903. Original article in Zhur. Opuitn. Agron. (Jour. Exp. Landw.), t. 4, kniga 2, p.163–187. 1903. Not seen.

(3) GILE, P. L.
1913. Lime-magnesia ratio as influenced by concentration. Porto Rico Agr. Exp. Sta. Bul. 12, 24 p., 4 pl.

(4) ——— and AGETON, C. N.
1913. The significance of the lime-magnesia ratio in soil analysis. *In* Jour. Indus. and Engin. Chem., v. 5, no. 1, p. 33–35.

(5) ——— ———
1914. The effect of strongly calcareous soils on the growth and ash composition of certain plants. Porto Rico Agr. Exp. Sta. Bul. 16, 45 p., 4 pl.

(6) GÖSSEL, Fr.
1904. Importance of calcium and magnesium salts for plants. (Abstract.) *In* Jour. Chem. Soc. [London], v. 88, pt. 2, Abstracts, p. 51. Original article in Verhandl. Gesell. Deut. Naturf. u. Ärzte, 75. Versamml. 1903, T. 2, Hälfte 1, p. 101–104. 1904. Not seen.

(7) HASELHOFF, E.
1893. Versuche über den Ersatz des Kalkes durch Strontian bei der Pflanzenernährung. *In* Landw. Jahrb., Bd. 22, p. 851–861.

(8) ———
1913. Über die Wirkung von Kalk und Magnesia bei der Ernährung der Pflanzen. *In* Landw. Jahrb., Bd. 45, Heft 4, p. 609–633.

(9) HOPKINS, C. G.
1910. Soil Fertility and Permanent Agriculture. 653 p., illus., maps. Boston, New York.

(10) JENSEN, G. H.
1907. Toxic limits and stimulation effects of some salts and poisons on wheat. *In* Bot. Gaz., v. 43, no. 1, p. 11–44, 33 fig. Literature cited, p. 42–44.

(11) KEARNEY, T. H., and HARTER, L. L.
1907. The comparative tolerance of various plants for the salts common in alkali soils. U. S. Dept. Agr. Bur. Plant Indus. Bul. 113, 22 p.

(12) KONOVALOV, I.
1907. On the question of the different correlations between lime and magnesia in the nutritive solution (theory of O. Loew). (Abstract.) *In* Exp. Sta. Rec., v. 19, no. 9, p. 827-828. 1908. Original article in Zhur Opuitn. Agron. (Russ. Jour. Exp. Landw.). t. 8, kniga 3, p. 257-280. 1907. Not seen.

(13) LEMMERMANN, O., EINECKE, A., and FISCHER, H.
1911. Untersuchungen über die Wirkung eines verschiedenen Verhältnisses von Kalk und Magnesia in einigen Böden auf höhere Pflanzen und Mikroorganismen. *In* Landw. Jahrb., Bd. 40, Heft 1/2, p. 173-254.

(14) LIPMAN, C. B.
1909. Toxic and antagonistic effects of salts as related to ammonification by Bacillus subtilis. *In* Bot. Gaz., v. 48, no. 2, p. 105-125, 5 fig. Literature cited, p. 124-125.

(15) LOEW, Oscar
1892. Ueber die physiologischen Functionen der Calcium-und Magnesiumsalze im Pflanzenorganismus. *In* Flora, Jahrg. 75 (n. R. Jahrg. 50), Heft 3, p. 368-394.

(16) ———
1903. The physiological rôle of mineral nutrients in plants. U. S. Dept. Agr. Bur. Plant Indus. Bul. 45, 70 p.

(17) MacDOUGAL, D. T.
1901. Practical Text-Book of Plant Physiology. 352 p., illus. New York, London, Bombay.

(18) MacINTIRE, W. H., WILLIS, L. G., and HARDY, J. I.
1914. The non-existence of magnesium carbonate in humid soils. Tenn. Agr. Exp. Sta. Bul. 107, p. 149-202, illus.

(19) MEURER, Reinhard.
1909. Ueber die regulatorische Aufnahme anorganischer Stoffe durch die Wurzeln von Beta vulgaris und Daucus Carota. *In* Jahrb. Wiss. Bot., Bd. 46, Heft 4, p. 503-567.

(20) MEYER, D.
1904. Untersuchungen über die Wirkung verschiedener Kalk- und Magnesiaformen. *In* Landw. Jahrb., Bd. 33, Heft 3. p. 371-404, pl. 11.

(21) ———
1910. Kalk- und Magnesiaversuche. *In* Centbl. Agr. Chem. Jahrg. 39, Heft 10, p. 679-694.

(22) NAKAMURA, T.
1905. Über die Wirkung einer starken Magnesiadüngung in Form von Bittersalz. *In* Landw. Jahrb., Bd. 34, Heft 1, p. 141-143.

(23) NATHANSON, Alexander.
1902. Ueber Regulationserscheinungen im Stoffaustausch. *In* Jahrb. Wiss. Bot., Bd. 38, Heft 2, p. 241-290.

(24) OSTERHOUT, W. J.
1908. The value of sodium to plants by reason of its protective action. *In* Univ. Cal. Pub. Bot., v. 3. no. 3. p. 331-340.

(25) PATTERSON, H. J.
1900 The occurrence and composition of lime in Maryland, together with a report of the results of experiments in testing its use in agriculture. Md. Agr. Exp. Sta. Bul. 66, p. 91-130, 2 pl. (maps).

(26) PEIRCE, G. J.
1903. A Text-Book of Plant Physiology. 291 p., illus. New York.
(27) PFEFFER, W. F. P.
1900. The Physiology of Plants . . . ed. 2., revised, translated and edited by A. J. Ewart. v. 1, Oxford.
(28) PISCIOTTA, F.
1913. Lime-magnesia ratio in the cultivation of grain. (Abstract.) *In* Exp. Sta. Rec., v. 30, no. 6, p. 519. 1914. Original article in Staz. Sper. Agr. Ital., v. 46, fasc. 10, p. 643–660. 1913. Not seen.
(29) REED, H. S.
1907. The value of certain nutritive elements to the plant cell. *In* Ann. Bot., v. 21, no. 84, p. 501–543, 2 fig. Bibliography, p. 540–543.
(30) RUSSELL, E. J.
1912. Soil Conditions and Plant Growth. 168 p. London, New York. Selected bibliography, p. 154–166.
(31) SCHULZE, Ernst, and GODET, Ch.
1908. The amounts of calcium and magnesium in plant seeds. (Abstract.) *In* Jour. Chem. Soc. [London], Abstracts, v. 96, pt. 2, p. 83. 1909. Original article in Ztschr. Physiol. Chem., Bd. 58, p. 156–161. 1908. Not seen.
(32) SEISSL, J.
1907. On the relation between the magnesium oxid and calcium oxid in the leaves of various plants during different periods of growth. (Abstract.) *In* Exp. Sta. Rec., v. 19, no. 2, p. 128–129. 1907. Original article in Ztschr. Landw. Versuchsw. Oesterr., Bd. 10, Heft 3, p. 88–121. 1907. Not seen.
(33) STEWART, Robert.
1911. A contribution to the knowledge regarding Loew's lime-magnesium ratio. *In* Jour. Indus. and Engin. Chem., v. 3, no. 6, p. 376–378.
(34) ULBRICHT, R.
1899. Vegetationsversuche in Töpfen über die Wirkung der Kalkerde und Magnesia in gebrannten Kalken und Mergeln. *In* Landw. Vers. Stat., Bd. 52, Heft 5/6, p. 383–430, 7 fig.
(35) VOELCKER, J. A.
1909. Field experiments, 1909. [Woburn experimental station]. Experiment with magnesia on wheat, 1909. *In* Jour. Roy. Agr. Soc. England, v. 70, p. 379.
(36) ———
1910. Pot-culture experiments, 1909, [Woburn experimental station]. 7. The influence of lime and magnesia in different forms on wheat. *In* Jour. Roy. Agr. Soc. England, v. 71, p. 346–347.
(37) ———
1912. Pot-culture experiments, 1910–11–12, [Woburn experimental station]. *In* Jour. Roy. Agr. Soc. England, v. 73, p. 314–338, 11 pl.
(38) WARTHIADI, D.
1911. The variation of plants under the influence of lime and magnesia. (Abstract.) *In* Exp. Sta. Rec., v. 26, no. 1, p. 35–36. 1912. Original published in German Veränderungen der Pflanze unter dem Einfluss von Kalk und Magnesia. 155 p., 49 fig. München, 1911. Inaugural-Dissertation.

(39) WHEELER, H. J., and HARTWELL, B. L.
1905. Magnesium as a manure. A few data concerning the proper relation of lime to magnesia. *In* R. I. Agr. Exp. Sta. 17th Ann. Rpt., 1903/04, p. 249–259.

(40) WILLSTÄTTER, Richard.
1915. Chlorophyll. *In* Jour. Amer. Chem. Soc., v. 37, no. 2, p. 323-345, 1 fig.

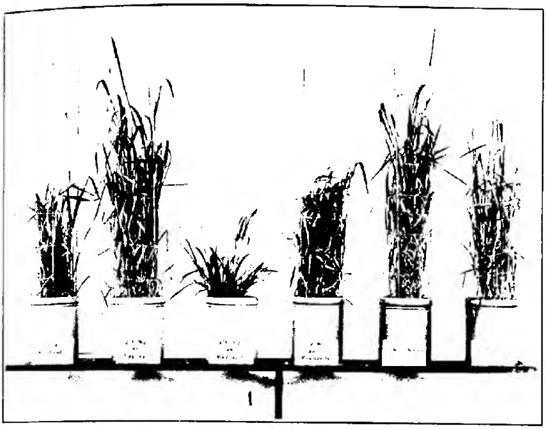
(41) WOLF, Wilhelm.
1864. Die Saussure'schen Gesetze der Aufsaugung von einfachen Salzlösungen durch die Wurzeln der Pflanzen. *In* Landw. Vers. Stat., Bd. 6, p. 203–250.

(42) WOODWARD, John.
1700. Some thoughts and experiments concerning vegetation. *In* Phil. Trans. [Roy. Soc. London], v. 21, 1699, p. 193–227.

PLATE LXXXIV

Fig. 1.—Growth of wheat in sand containing varying quantities of calcium and magnesium. The small growth of wheat in the pot marked "6% magnesium" is due to a detrimental physical effect.

Fig. 2.—Growth of alfalfa in sand containing varying amounts of calcium and magnesium.



1

2


Check
Sand only
Sand
after
Cow Peas
Sand
&
Alfalfa Rts.
1

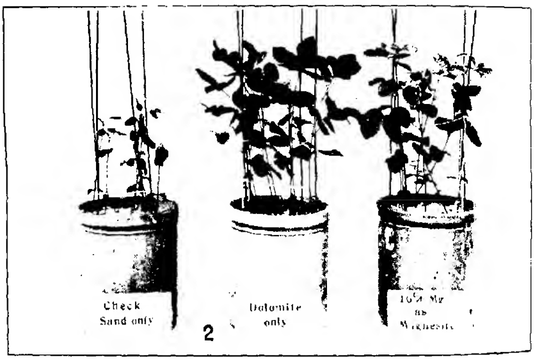

Check
Sand only
Dolomite
only
2

PLATE LXXXV

Fig. 1.—Growth of soybeans following a crop which had already absorbed most of the readily available calcium and magnesium.

Fig. 2.—Growth of soybeans in soil treated with magnesium. Note the sickly appearance of the top leaves in the right-hand pot, which is characteristic of treatment with large quantities of magnesium.